FIELD EVALUATION OF A NOVEL EXPOSURE ASSESSMENT STRATEGY USING RESPIRABLE COAL DUST EXPOSURES DURING HEAT PLANT COAL RECEIVING OPERATIONS

THESIS

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AFIT/GIH/ENV/09-M01

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Abstract

An exposure assessment strategy (EAS) determines the number of samples required to characterize an occupational health exposure's acceptability. A novel EAS (AFIT-EAS) was developed with the objective of maximizing the sensitivity for detecting unacceptable exposures, while minimizing the total number of samples needed. The purpose of this field evaluation was to use data from a comprehensive sampling campaign (SC) to compare the AFIT-EAS with two commonly used EASs: the Occupational Safety and Health Administration's (OSHA-EAS) and the American Industrial Hygiene Association's (AIHA-EAS). 10 randomly sampled replicates were selected from the SC. The number of samples selected per replicate was in accordance with each respective EAS's protocol. Results show that the true health risk assessment for the SC was evaluated as unacceptable; therefore, EAS conclusions matching this result were counted as successful. The OSHA-EAS of one (1) sample per replicate was the least successful with a maximum success rate of 20%. The AIHA-EAS of six (6) samples per replicate was equal to the AFIT-EAS of three (3) samples per replicate with a maximum success rate of 100%. The AFIT-EAS was found to be more accurate than the OSHA-EAS and equally accurate as the AIHA-EAS, while using only half as many samples.

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Dedication

I dedicate all my endeavors at AFIT, culminated by this capstone document, to the Almighty God, sovereign of the universe, the heavenly Father of my Lord Jesus Christ who has blessed me with every spiritual blessing in heavenly places in Christ our Lord. On the recollection of so many and great favors and blessings, am I determined to press into public notice this token of gratitude to the most important person in my life – Jesus.

It is my prayer of blessing for you whose eyes are now reading these words, that you incline your ear to wisdom, and apply your heart to understanding. For the Lord gives wisdom; from His mouth come knowledge and understanding; He stores up sound wisdom for the upright. Then you will understand righteousness and justice, equity and every good path. When wisdom enters your heart, and knowledge is pleasant to your soul, discretion will preserve you; understanding will keep you. May the God of hope fill you with all joy and peace in believing, that you may abound in hope by the power of the Holy Spirit, in the mighty name of Jesus, Amen!

Acknowledgments

I would like to express my sincere heartfelt appreciation to Major (Dr.) Jeremy Slagley. You are the encapsulation of humble genius. Your genuine interest and never-ending patience, which you showed toward the hair-brained rambling of this naïve student, will forever, garnish my highest respect. I will forever be grateful for your ever-positive attitude and encouragement throughout this graduate program and thesis process. The positive impact you have made into my life and future as a commissioned officer will reap a multitude of blessing for generations of Battens.

My gratitude also extends to members of my committee, Lieutenant Colonel (Dr.) David Smith and Major Dirk Yamamoto. To Dr. Smith, thank you for your instruction over the last year and a half. I hope that many lives will be saved as a direct result of your contributions to this research effort. To Maj Yamamoto, having one foot in the trenches as a fellow student, I cannot thank you enough for your willingness to leap on board near the end of this process. The finished product of this thesis is a reflection of their efforts.

I want to thank my classmates, Capt Daniel Sweeney and Capt Robert Schmidtgoessling, for the tremendous camaraderie we have shared over the short 18 months at AFIT. Your efforts were instrumental in the development of the Air Force Institutes of Technology's Exposure Assessment Strategy. In no small measure, do I owe gratitude for helping complete this chapter of my life and many of the chapters of this study.

I would like to thank my family. To my father and my mother, who never once doubted that I would be selected for AFIT, complete my degree and receive a commission, “It’s just expected”. Most of all, I would like to give special thanks to my one true love, my soul mate, my best friend, and my gift from heaven; to my beautiful wife and mother of my precious children - JNB. I would have never been able to complete this thesis without your dedicated support of our home and family. It is a miracle that I have someone with such an abundant amount of love, patience, support, understanding, and joy with which to share my life. I am amazed and excited for what the future holds for our family.

Timothy W. Batten

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List of Abbreviations

ACGIH®	American Conference of Industrial Hygienists
AF	United States Air Force
AFIT	Air Force Institute of Technology
AIHA	American Industrial Hygiene Association
BEE	Bioenvironmental Engineers
CFR	Code of Federal Regulations
DataRAM®	Thermo Electron Corporation's Personal Data-logging Real-time Aerosol Monitor – *personal*DataRAM®
DRI	Direct reading instrument
DryCal®	Bios DryCal® DC2-B, in conjunction with a DC-MC-1 attachment
EA	Exposure assessment
EAS	Exposure assessment strategy
GilAir5®	Gilian GilAir5® – Tri-Mode Air Sampler
GM	geometric mean
GSD	geometric standard deviation
HEPA	high efficiency particulate air
NIOSH	National Institute of Occupational Safety and Health
OEL	Occupational exposure limit
OSHA	Occupational Safety and Health Administration
PEL	Permissible exposure limit
PNOR	Particulates Not Otherwise Regulated, Respirable

PVC	polyvinyl chloride
REL	recommended exposure levels
TLV®	threshold limit value
TWA	time-weighted-average exposure
SEG	similarly exposed group or similar exposure group
PEL	permissible exposure limit
WBGT	Quest Temp °34, Thermal Environment Monitor (or Wet Bulb Globe Temperature used for any model of similar equipment)
WPAFB	Wright-Patterson Air Force Base
XRD	X-ray Powder Diffraction

FIELD EVALUATION OF A NOVEL EXPOSURE ASSESSMENT STRATEGY USING RESPIRABLE COAL DUST EXPOSURES DURING HEAT PLANT COAL RECEIVING OPERATIONS

I. Introduction

Background

Working with hazardous materials always presents a certain level of risk to the employee. The level of risk is determined by the duration and frequency of the exposure and by the severity and inherent toxicity of the material (Hewett, 2001). The United States Air Force (AF) Bioenvironmental Engineers (BEEs) are risk assessment and risk management specialists who protect AF personnel from occupational health hazards by performing exposure assessments. Currently, an exposure assessment (EA) can consist of a campaign of very complicated and costly exposure sampling involving the collection of multitudes of personal and area samples from a work environment to determine the concentrations of toxic gases, vapors, or particulates to which employees are exposed. However, an EA can be as simple as the application of professional judgment following a visual inspection of the work area. Due to this wide range of resources required on a case-by-case basis, to achieve the optimal assessment of risk, the need for a formal exposure assessment strategy (EAS) is evident.

An exposure assessment strategy (EAS) is the formal plan that provides the employer (AF unit commanders) an estimate of how many and what type of samples the industrial hygienist (BEE flight) may be required in order to adequately assess the industrial workplace hazards for which the employees are exposed (NIOSH, 1977).

Furthermore, the EAS provides the BEE with a decision scheme to determine whether occupational exposures warrant sampling (Tuggle, 1981), and if so, by means of sampling results, ascertain whether the health risk due to exposures is considered controlled or uncontrolled. Unfortunately, no single EAS fits every industry or corporation.

Currently there is no formal EAS universally employed by all BEEs throughout the AF. Traditionally, the BEEs have followed a worst-case compliance strategy based on the OSHA model. Mulhausen defines this approach to exposure surveillance as follows:

> "An attempt is made to identify the maximum-exposed workers in a group. One or a few measurements are then taken and simply compared with the [occupational exposure limit] OEL. If the exposures of the maximum-exposed workers are sufficiently below the OEL, then the situation is acceptable. This strategy provides little insight into the day-to-day variation in exposure levels and is not amenable to the development of exposure histories that accurately reflect exposures and health risk." (Mulhausen, et al., 2003)

In response to the health hazard risk from underestimating the true exposure due to small sample sizes, along with a lack of understanding of the day-to-day variation in exposure levels described by Mulhausen, the comprehensive exposure strategy was introduced in 1998. (American Industrial Hygiene Association, 1998) One comprehensive strategy, known as the American Industrial Hygiene Association (AIHA) EAS, recommends collecting a minimum of six measurements and then using a "Decision Statistic" (Murphy, 2006) as a threshold for exposure acceptability. The upper 95^{th} percentile has long been a commonly used decision statistic, (Jayjock, 1997; Leidel, et al., 1977; Rappaport, et al., 1981; Selvin, et al., 1987); however, the use of alternative threshold

levels of acceptability are not restricted to only the 95th percentile in the comprehensive model.

A criticism of the AIHA EAS is that the number of samples, six minimum, is excessively burdensome with regard to the limited available resources. However, this number could be reduced if a two-stage sampling approach was incorporated (Hewett, 2005). Taking this into consideration, a proposed EAS developed at the Air Force Institute of Technology (AFIT) utilizes a tiered approach. Tier-1 employs gas and vapor airborne concentration modeling to determine if an overexposure is possible. When the modeling in tier-1 cannot confidently rule out overexposure, tier-2 implements direct reading instruments (DRIs) to estimate an airborne exposure. If the assessment from the DRIs does not clearly demonstrate an acceptable or unacceptable characterization then tier-3 utilizes a planned strategy of traditional integrated sampling to further characterize the exposure.

Problem Statement

Because of ever-limited resources, AF BEEs collect only the minimum number of air samples required to derive a risk assessment for a hazardous process. For work processes that exhibit clearly unacceptable exposures, this approach can demonstrate the need for exposure control in the most hazardous of circumstances. Risk assessments based on few samples collected from a log-normally distributed exposure profile can often have a wide confidence interval due to processes and worker variability. A large upper confidence limit or worse, failing to recognize the lack of statistical confidence on the exposure assessment all together, can result in erroneously concluding exposures are within control limits, when in actuality, they may fail to meet safety standards. To a

lesser degree, there is a conversely associated problem of calling for costly control measures when the hazard is in fact sufficiently controlled. To address these problems, the AFIT EAS was developed not only to increase the confidence of the exposure assessments but also to keep the number of integrated analytical samples to a minimum, (for details refer to Appendix A: AFIT EAS).

An integral problem faced by every EAS is that achieving a high confidence in hazard characterization often requires a burdensome number of samples be collected. Conversely, if a minimalistic approach is taken, then accuracy suffers resulting in both a higher risk of instituting unneeded and costly controls or by allowing workers to be overexposed. Therefore, the BEE must consider the expenditure of resources for an EAS in the following three categories: 1) the costs of sampling, 2) the costs of controlling incorrectly classified hazards, which need not be controlled (α error), and 3) the costs of excess risk to health for not controlling incorrectly classified hazards, which should have been controlled (β error).

The focus of this thesis is to evaluate the efficacy of the AFIT EAS using actual AF exposure data. Because AF BEEs only collect minimal data on a single industrial process, the use of existing data would be insufficient to challenge the AFIT EAS. Therefore, a robust sampling campaign was designed and executed with the purpose of gathering enough data to define closely the true process exposure profile of an AF industrial process.

Several factors were considered in selecting an industrial task to assess. The task had to involve a hazardous material that could be measureable using an existing DRI and integrated sampling protocols. The results had to be comparable to accepted

occupational exposure standards. The industrial activity associated with the toxicant had to be frequent and predictable. Preferably, there had to be more than one worker performing the activity over the course of the campaign for between-worker and within-worker comparisons. Lastly, the anticipated exposure had to be greater than the limit of detection for both the DRI and the analytical methods yet not so overly great as to generate an obvious overexposure during the risk assessment. The AF process that most closely met these criteria was the activity of filling furnace bunkers with coal at the heat plants located on Area B and Area C at Wright-Patterson AFB.

Research Objectives

The objective of this field evaluation is to address the following questions related to the accuracy and efficiency of the AFIT EAS.

1. Does the AFIT EAS result in a correct risk assessment outcome more often than the OSHA compliance strategy?
2. Does the AFIT EAS reach the correct risk assessment outcome using fewer integrated samples than the AIHA model?
3. What benefits (if any) does the AFIT EAS bring in addition to relative increased accuracy and fewer samples?
4. What limitations (if any) does the AFIT EAS have which fails to outperform either the OSHA or AIHA EAS?

Focus and Scope

The AFIT EAS tier-1 is used to rule out gas and vapor exposures based on exposure modeling. This is a key benefit of the AFIT EAS, as screening exposures that

are clearly controlled will reduce the number of DRI and analytical samples collected. This also has the benefit of documenting the current work conditions at the time of the risk assessment for later comparison when processes change. Additionally, tier-1 models can be used to anticipate work frequencies or durations that would trigger tier-2 sampling. However, the goal of this study was to select a process beyond the tier-1 cutoffs. Additionally, tier-1 models can only be applied to gases and vapors. The exclusive sample collection of particulate exposures (coal dust) in this study cannot be applied to any of the tier-1 models for exposure characterization. Therefore, the focus of this field evaluation by design and limitation is restricted to tier-2 and tier-3 respectively, the DRIs and integrated sampling components of the AFIT EAS.

Methodology

The methodology of this study begins with the collection and analysis of air samples for establishing a baseline exposure profile. The evaluation and contrasting of the EASs follow, with random selections from the baseline data set in compliance with the decision logic and methodologies of each specific strategy.

Airborne dust and crystalline silica exposures were monitored among coal-fueled heat plant workers engaged in furnace bunker filling operations at two sites on Wright-Patterson Air Force Base (WPAFB). In line, integrated samples and DRI samples were simultaneously collected using one common sample train. One-minute average concentrations of respirable dust were logged using the Thermo Electron Corporation's Personal Data-logging Real-time Aerosol Monitor – *personal*DataRAM® (Thermo Electron Corp., Franklin, MA) with an attached cyclone to separate the respirable particles from total aerosolized dust. The respirable dust exposure was collected on a

pre-weighed filter cassette attached to the *personal*DataRAM® The filters were sampled and analyzed according to the National Institute of Occupational Safety and Health (NIOSH) Method number 0600 – Particulates Not Otherwise Regulated, Respirable (PNOR) and method number 7500 – Silica, Crystalline, by X-ray Powder Diffraction (XRD). NIOSH Method 0600 uses gravimetric analysis to determine total respirable concentration as a function of weight and air volume sampled. The same sample, through X-ray diffraction, determines the percentages of the three most common forms of crystalline silica to include quartz, cristobalite and tridymite.

The 2008 American Conference of Industrial Hygienists (ACGIH®) threshold limit value (TLV®) booklet (ACGIH, 2008) lists two distinct classifications of coal dust with individual respirable time-weighted averages (TWA). Established in 1995, the TWA TLV® for anthracite coal dust is 0.4 milligrams per cubic meter of air (mg/m^3), while bituminous coal dust has a TWA TLV® of 0.9 mg/m^3 (ACGIH, 2008). A bulk sample of coal from each of the heat plants was submitted for percentage of anthracite and bituminous coal content. The results were vastly different between the two heat plant samples even though coal is supplied from the same source (for further detail, please refer to Chapter IV Results). Due to the inconsistency reported in the bulk sample, the application of the anthracite coal standard of 0.4 mg/m^3 was used in this study with the total exclusion of the bituminous coal component.

The 2008 ACGIH® TLV® booklet lists the respirable TWA TLV® for crystalline silica at 0.025 mg/m^3 (note that between 2005 and 2006 ACGIH® withdrew tridymite and tripoli, while combining quartz and cristobalite into one TLV®, i.e. *Silica, Crystalline*) (ACGIH, 2008). Additionally, the ACGIH® gave crystalline silica an A2 designation

indicating it as a potential human carcinogen. Studies have shown that crystalline silica (α-quartz) may be present in coal dust by as much as 10% (Borm, 1997). For this reason, all bulk and air samples were also analyzed for crystalline silica content.

ACGIH® Exposure Limit Categories

The ACGIH divides its published exposure limits into three categories: the TWA for chronic exposures, the short-term exposure limit (STEL) for recognized acute effects, and the ceiling limit for "concentrations that should not be exceeded during any part of the work exposure" (ACGIH, 2008). While every chemical listed in the TLV® booklet has a specific TWA, not all chemicals, to include coal dust and silica, have STELs or ceiling limits. Nonetheless, the ACGIH recommends controlling all excursions above the TLV® in addition to controlling exposures below the 8-hour TLV® TWA. Specifically for hazardous substances without a published STEL or ceiling limit, the ACGIH recommends the application of two exposure levels to control excursions.

> "Excursions in worker exposure levels may exceed 3 times the TLV®-TWA for no more than a total of 30 minutes during a workday, and under no circumstances should they exceed 5 times the TLV®-TWA, provided that the TLV®-TWA is not exceeded." (ACGIH, 2008)

In addition to evaluating exposures using the TLV® TWA, this research effort accounted for excursion limits that exceeded three times the TLV® for greater than 30 minutes and those which exceeded five times the TLV®.

Assumptions

1. For the sake of applying the most stringent standard, coal dust was compared to 100% anthracite coal and 0% bituminous coal. However, it can be argued that some level of bituminous coal is always present.

2. Silica and coal dust are hazardous substances with the potential to cause adverse health effects if exposures are uncontrolled.
3. Probabilistic independence is assumed because exposures at the Area B heat plant are independent from exposures at the Kitty Hawk heat plant. Additionally, exposures on any given day are unrelated to the exposure from any day prior. However, exposures within the same sample event are interdependent to one another.

Implications

The implications for the adoption of the AFIT EAS are many. In general, a standardized EAS is needed because risk assessments made on a very few number of samples could yield conclusions that place workers at increased risk to injury and illness. Specifically, the tier-1 module provides a screening tool to reduce theoretically unnecessary sampling of gases and vapors through conservative exposure modeling calculations. The tier-2 module emphasizes the use of DRI, which provides immediate results. Together, tier-1 and tier-2 skill sets would enhance and improve the tactics, techniques and procedures needed for deployed and contingency operations though tangible garrison usage. Lastly, the standardized approach of the tier-3 integrated sampling module provides the BEE with a clear confidence interval on the exposure assessment so that the risk assessment is objective with a better understanding of the potential error in the determination.

Document Overview

The remainder of this thesis will offer the following sections: literature review, methodology, results and analysis, and conclusions and recommendations. The literature

review at Chapter II provides a synopsis of existing published knowledge pertaining to occupational health issues related to exposure assessment strategies. This includes a review of some of the key concepts for addressing and evaluating any EAS. A detailed discussion of the methodologies for the air sample collection and the process employed in the AFIT EAS field evaluation is found at Chapter III. Discussion along with the analysis of the results to answer the research questions are at Chapter IV. The thesis concludes at Chapter V with a summary of the results, their impact on prospective AF BEE doctrine and closes with the submission of further research options for the consideration of future students and researchers.

II. Literature Review

Chapter Overview

The purpose of the literature review is to provide a comprehensive appraisal of the current state of knowledge related to key components of the EAS through the evaluation of relevant source documentation. In addition, the literature review provides a framework to introduce, in more detail, the principle concepts vital to a clear understanding for which the research methodologies and conclusions are founded. This surveillance of the foundational practices in EAS, lead to the demarcation among what is accepted, disputed and yet unknown for which further research, such as this, can build.

Exposure Profile

The first fundamental principle required for both understanding and evaluating an EAS is the concept of an exposure profile. Hewett defines the exposure profile as:

> "The current distribution (i.e., probability density function) of exposures for a worker, or a group of workers that have been aggregated by similarity of work environment and work conditions. Typically, this distribution is well described using the lognormal distribution model."(Hewett, 2005)

Hewett links the notion of the lognormal distribution with the definition of an exposure profile. Random House Dictionary.com defines *lognormality* as, "noting or pertaining to a logarithmic function with a normal distribution, or the distribution of a random variable for which the logarithm of the variable has a normal distribution."(lognormality) The lognormal distribution has routinely been used to characterize environmental exposure sample data first by the empirical observations of coal dust exposures (Oldham, 1953) and was later expanded as a "general rule" for

describing exposure profiles of most environmental data (Esmen, et al., 1977). "The lognormal distribution model is often used when zero is the physical lower limit for possible values, large values occasionally occur, and the processes that generate or control exposures tend to interact in a multiplicative manner (Hewett, 2001)."

Accepting the assumption that the underlying exposure profile is lognormally distributed ultimately allows the application of parametric statistics to the exposure profile. The exposure profile for each worker or similarly exposed group (SEG) of workers is completely characterized by two fundamental components of the lognormal distribution called the geometric mean (GM) and geometric standard deviation (GSD) (Rock, 1982).

The GM is "a measure of central tendency [or average] for a lognormal distribution" (Leidel, et al., 1977). The GSD is "a measure of relative dispersion (variability) of a lognormal distribution" (Leidel, et al., 1977). Figure 1 illustrates the interaction of these key concepts by showing four hypothetical lognormal exposure profiles each with a constant GM of 1.0, yet with different GSDs. As the GSD increases, the exposure profiles become less and less symmetrical about the GM such that the curves become more skewed to the right by outliers. Another perspective on Figure 1, is that for the GM to remain fixed at 1.0 it takes a disproportionately large number of low samples (represented by the hump to the left of 1.0) to compensate for a few elevated exposures trailing further out from the GM to the right. Hewett suggests that GSDs can be categorized using a rule of thumb, such that, exposure variability less than 1.5 is considered low, between 1.5 and 2.5 is considered moderate, greater than 2.5 is high and over 4.0 is unusually high (Hewett, 2001).

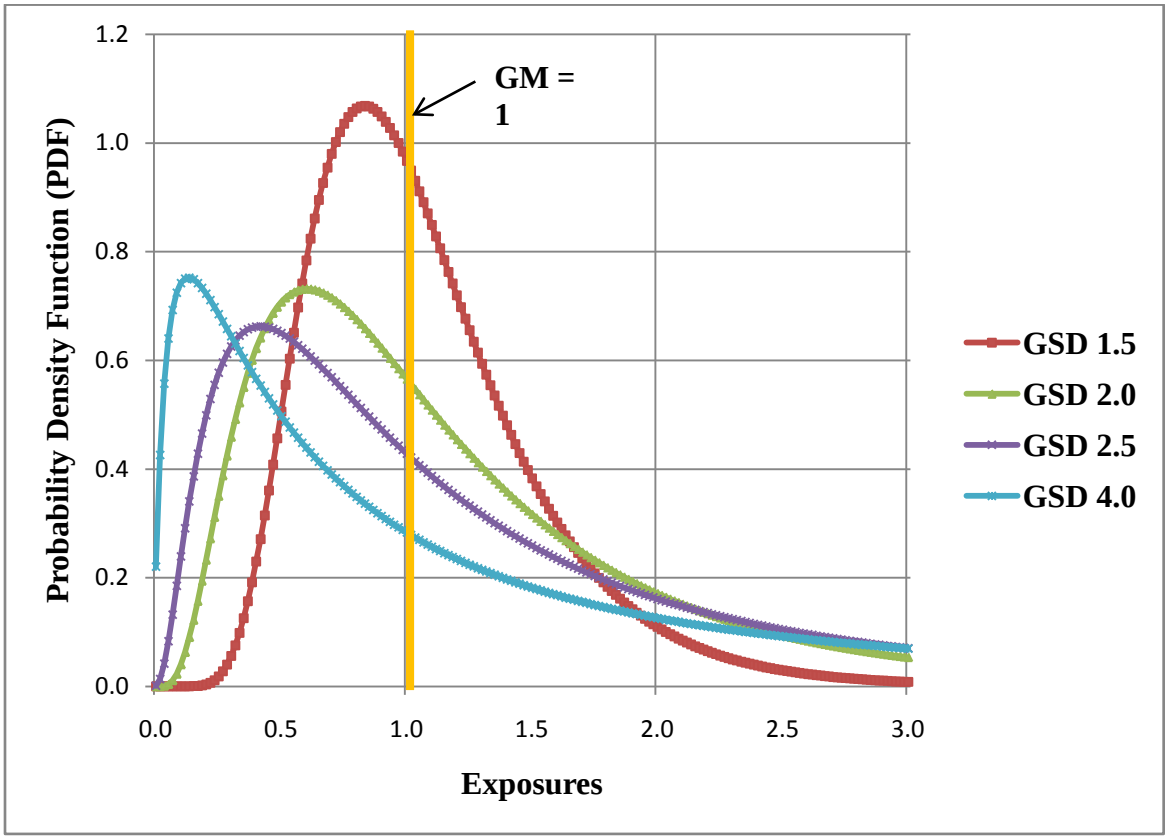

Figure 1: Lognormal PDF of various GSDs all with a GM of 1.0

In the context of industrial hygiene, exposure data is collected for the purpose of comparison to a standard with the intention of controlling the toxicological risk to exposed workers. To resolve the multitude of exposure standards and to generalize the illustration, Rock, defines a standardized exposure, x, as being:

> "…equal to the actual time-weighted-average exposure (TWA) divided by the applicable permissible exposure limit (PEL). The TWA is measured over the same period used to define the PEL, be it an instantaneous grab sample, a 5 to 15 minute short-term sample or an 8-hour full-period sample." (Rock, 1982)

Equation 1: Standardized Exposure, x

$$x = PEL/TWA$$

Additionally, theta (θ) is often used to represent the exceedance fraction, defined as the "the fraction of full-shift, time weighted average (TWA) exposures that exceeds the exposure limit; [or] the fraction of an exposure profile that exceeds the exposure limit." (Hewett, 2005) The exposure profile can now be defined if any two of the three parameters is known: (GM, GSD), (θ, GSD), or (x, GSD) (Rock, 1982).

The last fundamental concept used in the evaluation of the EAS, covered in this section, is the 95th percentile ($X_{0.95}$). The 95th percentile is the value in which 95% of a group (or the population) is included. In the case of a comprehensive exposure assessment, the group in question is the SEG. Therefore, the estimate of the upper $X_{0.95}$ of the exposure profile of the SEG is judged in relationship to the occupational exposure level (OEL) as a means for determining whether the exposure is controlled or uncontrolled as summarized in Table 1, reproduced from the AIHA Strategy (Mulhausen, et al., 2003).

Table 1: Exposure Categorization: Based on an Estimate of the $X_{0.95}$ and the OEL

Category	Statistical Interpretation	
	Based on Exceedance	Based on $X_{0.95}$
4	> 5% exceedance of the OEL	$X_{0.95}$ > OEL
3	> 5% exceedance of the 0.5 x OEL	OEL > $X_{0.95}$ > 0.5 x OEL
2	> 5% exceedance of the 0.1 x OEL	0.5 x OEL > $X_{0.95}$ > 0.1 x OEL
1	Little to no exceedance of the 0.1 x OEL	$X_{0.95}$ < 0.1 x OEL

Hewett categorized descriptively the exposures as uncontrolled, poorly controlled, controlled, well controlled, or highly controlled from the AIHA's statistical interpretations. Table 2 summarizes Hewett's classification system (Hewett, 2005).

Table 2: Exposure Categorization: Qualitative Description

Category	Exposure Category	Qualitative Description	Recommended Statistical Interpretation
0	uncontrolled	A large percentage of the exposures exceed the OEL.	$P(c > OEL) >> 0.05$
1	poorly-controlled	Exposures frequently exceed the OEL.	$P(c > OEL) > 0.05$
2	controlled	Exposures infrequently exceed the OEL.	$P(c > OEL) \leq 0.05$
3	well-controlled	Exposures infrequently exceed 50% of the OEL and rarely exceed the OEL.	$P(c > 0.5 \times OEL) \leq 0.05$ $P(c > OEL) \leq 0.01$
4	highly-controlled	Exposures infrequently exceed 10% of the OEL.	$P(c > 0.1 \times OEL) \leq 0.05$

These fundamental statistical concepts are vital to the understanding of the field evaluation of the three EAS's. However, for additional concepts and background for further insight, see Appendix A: AFIT EAS. While these statistical concepts are the root from which the field evaluation stems, the individual distinctions of each EAS, covered in the next section, branch forth from these common principles.

Compliance and Comprehensive Exposure Assessments

The field evaluation of the AFIT EAS by comparison with the OSHA EAS and AIHA EAS is rooted in the philosophical comparison between a compliance methodology and a comprehensive methodology of exposure assessment, which are the underpinnings of the OSHA EAS and the AIHA EAS, respectively. As mentioned in Chapter I, some of the distinctive elements of the compliance strategy are that it relies heavily on a point estimate of exposure in reference to the maximum risk employee (MRE) (Hewett, 2001), also known as the worse case exposure, with the purpose of maintaining compliance with a PEL. However, Mulhausen concedes that for

organizations with limited funding, the worst-case approach may be an appropriate starting place (Mulhausen, et al., 2003).

In contrast, the comprehensive strategy elevates the question from "Are we in compliance with the PEL today?" to a more responsible question, "Are we in compliance with all OELs every day?" (Hewett, 2008)

Mulhausen defines the comprehensive strategy as follows:

> "The comprehensive strategy is directed at characterizing and assessing exposure profiles (exposure average and variability) that cover all workers, workdays, and environmental agents. These exposure profiles are used to picture exposures on unmeasured days and for unmeasured workers in the similarly exposed group [SEG]. In addition to ensuring compliance with OELs, this strategy provides an understanding of the day-to-day distribution of exposures. Exposure assessment findings can be used to address present-day health risks and construct exposure histories. If a historical database is maintained, the exposure assessment data may be used to address future health issues for individual workers and/or groups of workers. In the latter case, the data may be used to support epidemiological studies."(Mulhausen, et al., 2003)

One of the fundamental distinctions debated between these two methodologies is the intentionally biased assessment of the MRE or by random sampling the assessment of the exposure profile of a SEG. However, this argument is not new. Decades ago, industry leaders discussed these same questions, "Should monitoring efforts be directed toward characterizing worst-case exposures? Should monitoring be done randomly, systematically, or based on professional judgment?" (Roach, 1987) Today there is still no universally accepted answer to these questions. However, to evaluate properly the benefits and limitations of these strategies, an understanding of their original motivation gives perspective to the circumstances best suited toward their service.

The compliance viewpoint traces its beginnings to a time before the development of personal monitors when the sheer physical difficulty of collecting a sample was the

driving factor toward surveillance using short grab or partial period samples. Rappaport relates,

> "Because monitoring was so difficult in those days, occupational hygienists attempted to identify highly exposed individuals and to ascertain whether their exposures were in the acceptable range, thereby placing an upper bound on the exposure for the entire group. This bias towards high levels, referred to as worst-case sampling, became so deeply rooted in professional practice that it persisted after the development of personal monitors, (Leidel, et al., 1977; Roach, et al., 1967) and is still encouraged in some quarters (Hewett, 1997). The practice probably continues because worst-case sampling is expedient within the confines of compliance testing." (Rappaport, 2000)

Rappaport outlines four reasons that worst-case sampling should be discouraged. First, studies indicate that hygienists are often inconsistent in successfully classifying exposures as high, medium or low based upon observation (Kromhout, et al., 1987; Post, et al., 1991). Second, the worst-case worker must be selected *a priori*, therefore, the unpredictability of key determinants of exposure such as the process, the duration, the environment, and the worker, can confound the anticipated worst-case worker as opposed to the subsequent true worst-case worker (Olsen, et al., 1994; Olsen, et al., 1994). Third, statistical tools are invalidated by the deliberate biasing of results (McClave, et al., 2008). Lastly, a statistically invalid exposure assessment leads to an equally invalid risk assessment (Ulfvarson, 1983; Olsen, 1996).

The compliance assessment strategy justifies these shortcomings by presenting the logical argument that if the maximum risk worker is sufficiently protected then the entire cohort of fellow workers is adequately protected. Moreover, if the maximum risk worker's exposure assessment is found within occupational exposure limits, therefore, it is reasonable to assume that all similarly exposed workers are likewise within limits. Hewett describes these shortcomings and benefits as follows:

> "The ability of industrial hygienists to reliably select one or more maximum risk employees from an exposure group has been questioned by several researchers. Furthermore, the NIOSH strategy will not reliably detect unacceptable work environments, even when the true exceedance fraction greatly exceeds 0.05 (Tuggle, 1981). Consequently, one should view the NIOSH scheme as the basis for a minimalistic exposure monitoring program that is best suited for auditing work environments where exposures were previously determined, by a comprehensive exposure assessment, to be controlled, well-controlled, or highly-controlled. Nonetheless, for initial evaluations or where resources are limited or re-sampling intervals are broad, the MRE concept is still recommended and commonly used by industrial hygienists as a means of efficiently determining the acceptability of the work environment for the members of an exposure group." (Hewett, 2001)

Another perspective to a potential pitfall of the worst-case worker strategy relates to a gradual shifting away from the worst-case strategy in favor of a representative or a random strategy.

> "Sampling strategies are often targeted toward anticipated worst case exposures... If assessment strategies changed during the course of a study from monitoring worst case exposures to sampling workers randomly (where the biased results are likely to have yielded higher levels than what would have been obtained had random sampling been conducted), (Ulfvarson, 1983; Olsen, 1996), then it is also possible that exposures could have seemed to decline even when they remained unchanged." (Symanski, et al., 1998)

A conceivable scenario is easily envisioned that fits nicely with Symanski's findings. A hypothetical industrial hygienist chooses an MRE as a matter of expediency, possibly anticipating a controlled exposure, however, later finds the exposure to be higher than first expected. Therefore, due to the absence of a formalized EAS, and in the name of "professional judgment", additional sampling is conducted using a strategy involving workers that are more representative or even a random selection of workers. While nothing has been done to reduce the workplace exposure, this revised strategy confirms the original expected level of exposure. Although the costs of additional sampling were

increased, the overall cost to the organization is minimized when weighed against with the cost of an engineering control or the establishment and sustainment of a respiratory protection program. While the questionable motives of this hypothetical industrial hygienist would be difficult to objectively evaluate, Symanski's findings show the plausibility of such a practice. The argument can be made that in light of the ABIH code of ethics (American Board of Industrial Hygiene, 2007), a "Sample-Until-You-Get-What-You-Want" assessment strategy is unlikely; however, the establishment of a formal EAS by an organization lacking one would contribute toward the limitation of potential (un)professional judgment.

There are, however, proposed benefits to the compliance exposure strategy. Mulhausen concedes that for organizations with limited funding, the worst-case approach may be an appropriate starting place (Mulhausen, et al., 2003). Hewett give a number of circumstances for which non-representative sampling have application.

> "Practically speaking, however, non-representative sampling has its uses. It is both reasonable and efficient to collect measurements solely on days of expected maximal exposure and/or solely from employees known or suspected to routinely experience the greatest exposures. It is also reasonable in many industrial environments to collect measurements in campaign fashion (i.e., on consecutive days), rather than in a strictly random fashion, because in most cases there is little serial correlation between measurements (Symanski, et al., 1994). When evaluating exposures relative to a short-term OEL or ceiling limit OEL, the usual strategy is to purposefully sample during periods that are representative of peak or maximum probable exposures (Mulhausen, et al., 1998; Leidel, et al., 1977)." (Hewett, 2001)

Those who follow a comprehensive exposure assessment strategy go to great lengths to remain as random in the selection of a worker within an SEG as possible. During an exposure assessment of welders, Susi conveyed this idea, "The importance of not biasing the collected data by selecting workers who might represent 'worst case' or

'best case' exposure scenarios was emphasized during training and at opening meetings." (Susi, et al., 2000) She went on to describe that this did, however, involve guidelines to selecting workers that would be engaged in welding for a pre-established minimum duration. Additionally, due diligence was taken to select workers which would perform "typical" or representative work. The random nature of test subject selection did not inhibit qualifying the pool of workers to meet the goals of the sample protocol.

Chapter Conclusion

In summary, survey of the published literature shows that the benefits of the compliance strategy tend to outweigh the limitations of additional random sampling it requires. Due to a preponderance of data in favor a comprehensive EAS, the AFIT EAS was designed foundationally as a comprehensive strategy.

Whereas the statistical tools and exposure classifications introduced in this chapter can be extremely useful in categorizing and describing an exposure profile in relationship to an OEL, the comprehensive exposure strategy is not enforceable regulatory under US Law. Interim Guidance 48-146, dated 14 March 2003, supplement to Air Force Instruction (AFI) 48-145, *Air Force Occupational Health Program*, provides standardizes procedures for the collection, analysis, management, and communication of occupational health information. Also, it gives some guidance similar to the concepts addressed in this chapter regarding the use of statistical tools and guidelines for sampling. However, at the time of this writing there was currently no official Department of Defense or Air Force policy which implements an EAS or directs the classification of exposure profiles using exceedance fractions or upper $X_{0.95}$. For this reason, the study

was undertaken to validate the efficacy and economy of the AFIT EAS for the consideration of the Air Force Medical Support Agency and BEE Corporate Board.

III. Methodology

Introduction

This chapter will discuss and describe the study methodology including the sample data collection procedure, data analysis, and EAS comparison. The chapter begins with air sample collection that was foundational to the subsequent EAS evaluation and comparison. The driving questions during the exposure assessment portion were, "What is the true nature of this exposure?" and "Are workers overexposed and if so how often?" To answer these questions, exposure criteria had to be established.

Exposure Criteria

Several governmental institutions and organizations publish exposure standards. This study looked at the three most common occupational health standard propagators: ACGIH, OSHA, and NIOSH. The 2008 ACGIH® TLV® booklet lists the respirable (based on cyclone sampling) TWA for crystalline silica at 0.025 mg/m^3, with an A2 designation indicating it as a potential human carcinogen (ACGIH, 2008). In 2006, the ACGIH® combined quartz and cristobalite into a single TLV® TWA under the heading crystalline silica. As part of the reclassification, two less common forms were withdrawn – tridymite and tripoli (ACGIH, 2008). Therefore, analytical results for crystalline silica are listed as quartz and cristobalite, found at Appendix B: Sample Results.

The Occupational Safety and Health Administration (OSHA) permissible exposure limit (PEL) standard for an 8-hour TWA for crystalline silica (as respirable quartz) is calculated using a formula found under the general industry standard for mineral dusts at Table Z-3 of 29 Code of Federal Regulations (CFR) 1910.1000. The formula generates a specific standard for the dust exposure based on the silica content

given as 10 mg/m^3 divided by the value "%SiO_2 + 2". The highest quartz level collected during this study was 2.2% SiO_2 (see Appendix B: Sample Results, for details). This percentage level would translate to an exposure limit of 2.4 mg/m^3 (as seen in Equation 2). This PEL is two orders of magnitude less protective than the ACGIH® TLV® of 0.025 mg/m^3.

Equation 2: Calculation for Silica PEL

$$\frac{10\ mg/m^3}{2.2\%\mathrm{SiO_2} + 2} = \frac{10\ mg/m^3}{4.2\%\mathrm{SiO_2}} = 2.4\ mg/m^3$$

Coincidently, the OSHA PEL 8-hour TWA for coal dust, containing less than 5% silica, found as well in Table Z-3 is also 2.4 mg/m^3. The 2008 ACGIH® TLV® for respirable coal dust is composed of anthracite coal dust at 0.4 mg/m^3 and bituminous coal dust at 0.9 mg/m^3, each significantly more stringent than the OSHA PEL. (ACGIH, 2008)

NIOSH establishes recommended exposure levels (RELs) based on human and/or animal toxicological data. While compliance with federal OSHA standards is obligatory, RELs, as the name implies, are guidelines based on both health effects and the technological feasibility for controlling workplace exposures at the proposed levels (NIOSH, 2005). The NIOSH REL TWA for respirable crystalline silica is 0.05 mg/m^3, double the ACGIH® TLV®. The NIOSH REL TWA for coal dust in general is 0.9 mg/m^3 without regard for the anthracite or bituminous varieties.

Table 3: Comparison of Exposure Standards

Institution	Terminology	Constituent	Limit (mg/m^3)
ACGIH®	TLV®	Coal	0.4
		Silica	0.025
OSHA	PEL	Coal	2.4
		Silica	2.4
NIOSH	REL	Coal	0.9
		Silica	0.05

Based on the most conservative of the exposure limits, summarized in Table 3, the ACGIH® TLV® for silica at 0.025 mg/m^3 and the ACGIH® TLV® anthracite coal dust at 0.4 mg/m^3 were used in this study.

Methodology for Sampling

Coal handlers at each of the two heat plants on Wright-Patterson Air Force Base (WPAFB) were the subjects of the air-sampling portion of this study from 17 Dec 2008 – 4 Jan 2009. The heat plant at building 1240 in Area C supports the heating of facilities in both Area C and Area A, of WPAFB. The heat plant at building 770 in Area B supports only Area B facilities; however, it supplies hot water in addition to ambient heat. Coal is delivered to each plant by truck, Monday through Saturday, alternating each week between the two heat plants. During the day shift, the coal is unloaded directly into an underground hopper (#2 in Figure 2). By means of a series of conveyor belts (#3 in Figure 2), coal is transported to the top of the heat plant into the bunkers situated directly over the furnaces (#4 in Figure 2). One of the series of conveyor belts has the option of depositing or retrieving coal via storage silos (#5 in Figure 2) located between the hopper and the bunkers. On days that coal is not delivered by trucks to the hopper, a bulldozer is used to fill the hopper from an outdoor mound of coal (#1 in Figure 2). If coal cannot be

transported from the hopper to the bunkers (via dotted line illustrating underground conveyor belt in Figure 2), then coal from the storage silos (#5 in Figure 2) can be used as a backup. Coal drawn from the silos is much drier and dustier than coal delivered by truck or from the storage mound. Note that Figure 2 designations are ordered by the progressed of coal starting at the outside mound (#1) to the underground hopper (#2) transported via conveyor belts (#3) primarily to the furnace bunkers (#4) but with the option of replenishing the silos (#5).

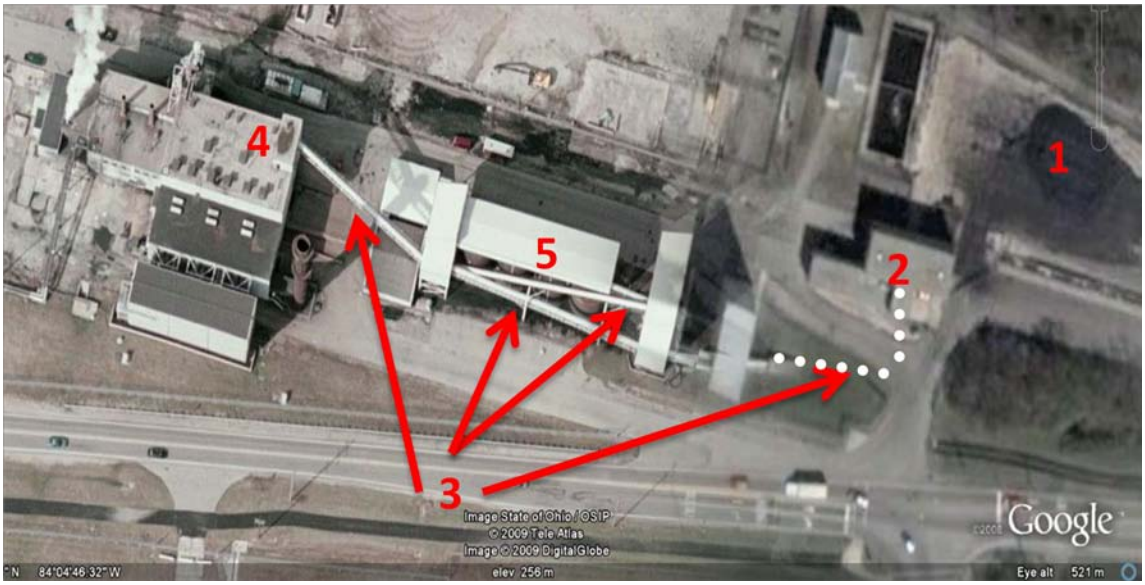

Figure 2: Building 770 Heat Plant Area B (Google, 2009)

The heat plant operates on three, 8-hour shifts; however, it is during the day shift that one coal handler fills the bunkers. The duration of the filling process is dependent on the demand for heat and hot water from the day prior, which is based on outdoor temperature, the day of the week, and whether the bunker was filled fully the day before. The range in duration of the filling process during the sampling campaign was from 39 to 216 minutes.

The worker manually positions a shuttle truck to fill coal evenly across the length of the bunker house (approx 110 ft long). The Area B facility's worker must leave the main filling area every 15 – 20 minutes to monitor and clear a grate that filters large chunks of coal. Except for these 2 – 3 minute absences, the coal receiver is in the bunker house exposed to the ambient dust levels for the duration of the process.

Twenty-six personal breathing-zone air samples for respirable coal dust and crystalline silica were collected from heat plant personnel engaged in filling the furnace bunkers at the two coal powered heat plants. In line, integrated air samples and DRI samples were simultaneously operated using one common sample train. One-minute average concentrations of respirable dust were logged using the DataRAM® with an attached cyclone (model GK 2.05) to separate the respirable particles from total aerosolized dust.

The total respirable dust exposure was collected on pre-weighed 5.0-µm pore size, polyvinyl chloride (PVC) filters (SKC, Inc., Eighty-four, PA) supported by a cassette filter holder attached to the DataRAM®. The filters were sampled and analyzed according to the NIOSH method 0600 – PNOR, Respirable and 7500 – Silica, Crystalline, by XRD. A portable air-sampling pump, the Gilian® GilAir5® – Tri-Mode Air Sampler, (Sensidyne LP, Clearwater, FL) was used to draw the sample through the DRI and the filter cassette. Air was drawn at a flow rate between 2.66 to 2.77 liters per minute (L/min) as outlined by NIOSH method 0600 and 7500 and prescribed by the instruction manual for the DataRAM's® GK 2.05 cyclone. Method 0600 uses gravimetric methods to determine total respirable concentration as a function of weight and air volume sampled. Using the same sample, X-ray diffraction determines the percentages

of the three most common forms of crystalline silica to include quartz, cristobalite and tridymite. Bulk samples were collected and analyzed using polarized light microscopy to determine the percentage of bituminous and anthracite coal. The high variability in the bulk sample results prevented the use of a synthetic mixed sample exposure limit. Therefore, the most stringent standard using the ACGIH® TLV® for respirable anthracite dust of 0.4 mg/m^3 was applied, without bias, to all sample analysis for coal dust.

Pre- and post-calibration measurements for the GilAir5® flow rate were measured using the Bios DryCal® DC2-B (Bios International Corporation, Butler, NJ), in conjunction with a DC-MC-1 frictionless piston attachment, serial number 100664 (DryCal). Pre- and post-calibration flow rates were derived using an average of 10 consecutive flow measurements. All pre- and post-calibrations were performed the same day of the sample event. All post-calibrations were within 10% of the pre-calibration reading. A detailed tabulation of the flow rates, calibration and sample volumes can be found at Appendix D: Tabulated Sample Data, Table D1 and Table D2. As part of the pre-calibration procedures, the DataRAM® was zeroed using a high efficiency particulate air (HEPA) filter according to manufacture instructions with a maximum pre-calibration concentration of 0.004 mg/m^3. During the post-calibration sequence, the DataRAM's® zero calibration was again checked using the HEPA filter with a maximum post-calibration concentration of 0.028 mg/m^3.

Following each post-calibration, the DataRAM's® GK 2.05 cyclone was dismantled and cleaned so that the following pre-calibration would be as low as reasonably achievable. Figure 3 depicts the typical configuration used in each calibration event.

Figure 3: Calibration Configuration

Two sample blanks were submitted in conjunction with the above air samples. One blank sample was a field blank, in which the cassette was taken 4 Jan 2009 into the field and exposed to all ambient conditions, as were the two used samples cassettes. The second blank was a trip blank and only exposed to the same shipping and storage conditions between the manufacture, storage, and the analytical lab. Neither blank sample had measureable contamination above the limit of detection.

In addition to the DataRAM®, a Quest Temp °34®, Thermal Environment Monitor, (Quest Technologies Inc., Oconomowoc, WI) (WBGT) with probe sensor attachment, was used to log the one-minute average relative humidity. As the humidity increases, the DataRAM® over-responds to the additional moisture content of the particle. (Chakrabarti, et al., 2004) A correction factor was then applied to resolve variations in relative humidity.

A variety of equipment and supplies were used to collect the exposure data of this study. Table 4, summarizes the apparatus and collection media.

Table 4: Apparatus for Sample Collection

Apparatus/ Supplies	Manufacturer	Model	Serial Number
DataRAM®	Thermo Electron™	PDR-1200	5999
GilAir5®	Gilian™	800885	13873
DryCal®	Bios International™	DC2-B	100966
WBGT	Quest Technologies™	Temp °34®	TEG040172
Sample Filter	SKC, Inc. ™	5.0-µm, 37-mm, PVC	Unique to each cassette

Methodology for EAS Evaluation

Results from the sampling campaign were listed chronologically in a spreadsheet table in Microsoft™ Excel® (Microsoft Corp., Seattle, WA) (Excel®). Using a random number command [=Rand ( )], random numbers corresponding to each of the 26 sample events were generated. The sample event pair with the largest random number generated was selected as the single representative sample. Each sample was replicated 10 times with a new batch of random numbers. Therefore, the OSHA EAS, which calls for one integrated sample, had 10 uniquely picked random numbers associated with one of the 26 available sampling events. Similarly, the AIHA EAS, which calls for six samples, had six sets of 10 uniquely paired random numbers, such that any of the 26 sample events could be chosen each round.

Unique to the AFIT EAS was the explicit use of DRI data in the first stage of three samples. This allowed for the application of excursion limits as well as TWA limits. The optional second stage selects three additional random samples from the

integrated sample analysis, in the event that there are any inconclusive sample results from the DRI data.

Assumptions

Spiked samples with a known mass for evaluating the analytical laboratories' accuracy and precision were not accomplished. Nor was there a way to split samples between two different labs for comparison. Laboratory results were assumed valid.

IV. Results and Analysis

Chapter Overview

The purpose of this chapter is to present the results and analysis of this research. As such, the data collected from the survey methods described in chapter III are presented in this chapter. The presentation of the findings includes an analysis of the sampling campaign as well as an analysis of the exposure assessment strategies.

Analysis of Sampling

The sample analysis consists of both the analytical results and the DRI results. The analytical results were for air samples at the breathing-zone and bulk coal samples. Raw results were converted to process mean concentrations and an 8-hour TWA by standard calculations so that inferences with regard to exposure limits could be assessed. The 8-hour TWA, when applied to a partial period sample, relies on the assumption that there is zero exposure to the agent for the remainder of the work shift. For the sake of research, the task-TWA (the TWA spanning the duration of the task regardless of the length of exposure) was also used for a side-by-side evaluation to simulate exposures for which the zero exposure assumption would be judged invalid.

Analytical Results

The analytical results for the sampling campaign for personal and bulk samples were received 3 February 2009 and 18 February 2009, from Bureau Veritas North America, Inc. under work order No.: 09010407, reference FA8900-07-A-9002IWPAT AFB/09N040. Copies of the results can be found at Appendix B: Sample Results.

By using a polarized light microscope, Bureau Veritas reported the bulk sample from the Area B heat plant as containing 90% anthracite coal and 10% bituminous coal. Conversely, the bulk sample from the Area C heat plant contained 5% anthracite coal and 95% bituminous coal. Due to this wide range in the constituency of the coal, the more stringently regulated anthracite coal was used as the sole agent of exposure.

Bureau Veritas reported the average concentration in mg/m^3 by taking the weight of coal dust in milligrams and dividing it by the volume of air sampled in cubic meters, understanding that 1000 liters equals one cubic meter. Using this average concentration, multiplied by the task duration in minutes, then divided by 480 minutes (8 hours) derives the 8-hour TWA. A detailed tabulation of the task and 8-hour TWA concentration results can be found at Appendix D: Tabulated Sample Data, Table D3.

Equation 3: Stepwise 8-hour TWA Calculation

$$\frac{\mu g\ Coal\ Dust}{1000} = mg$$

$$\frac{Liters\ Sampled}{1000} = m^3$$

$$\frac{mg}{m^3} = Average\ Concentration$$

$$(Avg. Concentration * Duration\ Sampled)/480\ minutes = 8 - hr\ TWA$$

DRI Results

The DataRAM® results were collected concurrently with the analytical samples. The 8-hr TWA and the average concentration were calculated in the same way as the analytical sample results. However, rather than having a single average concentration for

the entire period, the DataRAM® logged a 1-minute average concentration for each minute of exposure. The duration for the DataRAM® equaled that of the analytical samples (exceptions are covered in the limitations section of this chapter). These 1-minute averages were summed to derive an uncorrected overall mean similar to the overall mean calculated with the analytical samples. The uncorrected mean concentration was then adjusted for relative humidity by using the following formula (Chakrabarti, et al., 2004).

Equation 4: Relative Humidity Correction Factor

$$RH\ Corection\ Factor = 1 + \frac{0.25 * RH^2}{1 - RH}$$

where

RH = Relative Humidity (as a decimal)

In addition to correcting for relative humidity, compensation can also be made for differences in density, refractive index, and median particle size (O'Shaughnessy, et al., 2002); however, this would have required the use of additional equipment, unavailable at the time of the survey. In addition, so long as the DRI measurements are corrected by gravimetric results, as was done in this survey, the adjusted response can be assumed accurate.

Relative Humidity Correction Factor

The WBGT's clock was synchronized to the DataRAM® so the logged 1-minute average relative humidity results could be paired with the 1-minute average concentration results. The final adjusted task TWA and 8-hr TWA concentrations for the DRI samples are referenced at Appendix D: Tabulated Sample Data, in Table D4. A consolidated

summary of the analytical and DRI results for both the task TWA and 8-hour TWA is provided in Table 5.

Table 5: Summary of Percent Exceedance for Analytical and DRI Results

	Analytical Results		DRI Results	
	> Task TWA.	> 8-hr TWA	> Task Conc.	> 8-hr TWA
# over 0.4 mg/m^3	16	2	13	2
% Exceedance	61.5%	7.7%	50.0%	7.7%

By dividing the average concentration of the analytical results by the average concentration of the DRI results, a conversion factor is obtained which can then be applied to the 1-minute average concentration log from the DataRAM®. The range of the conversion factors was from 0.58 to 3.51; therefore, an average conversion factor was unfeasible. A detailed list of the correction factors for matching the DRI data to the analytical concentration data is included at Appendix D: Tabulated Sample Data, in Table D4. Consequently, the adjusted 1-minute average analytical concentration was graphed in the same manner as the DRI data. An example from the first day of sampling is provided in Figure 4. Note: all graphs can be found at Appendix C: Exposure Assessment Graphs.

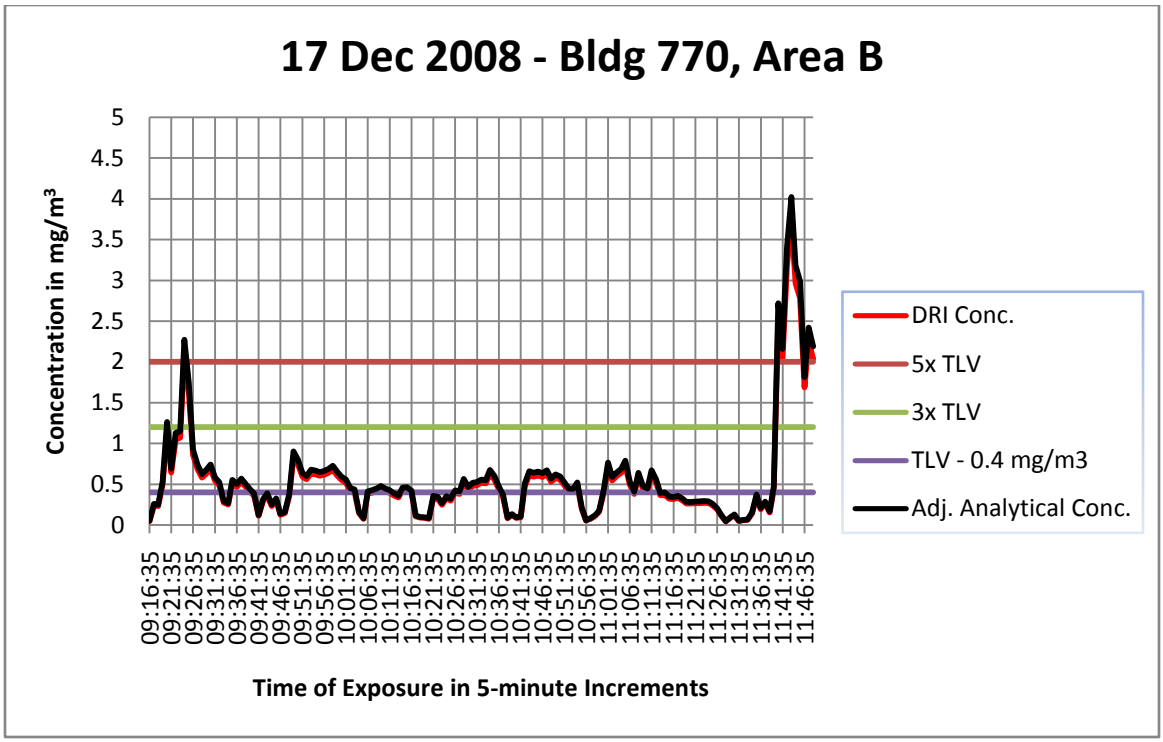

Figure 4: Visual Characterization of 1-Minute Average Concentration Results

Excursion Limits Results

By adjusting the DRI sample to equal the analytical sample, excursion limits can be assessed for both DRI data and analytical data. Both the cumulative 30-minute exceedance of three times the TLV®, equating to 1.2 mg/m^3, and the instantaneous exceedance of five times the TLV®, equating to 2.0 mg/m^3, were evaluated. A detailed list of the Excursion Limit Results for DRI and Analytical Samples is at Appendix D: Tabulated Sample Data, Table D5: Excursion Limit Results for DRI and Analytical Samples. The summary of the excursion limit results is in Table 6 below.

Table 6: Summary of Excursion Limit Results

	DRI	A.S.	DRI	A.S.
	> 3x TLV®	> 3x TLV®	> 5x TLV®	> 5x TLV®
# over Excursion Limit	1	1	13	15
% Exceedance	3.8%	3.8%	50.0%	57.7%

Analysis of EAS and Sampling Campaign

An analysis of the sampling campaign (SC) was conducted to establish a reference point for the evaluation of each of the EAS. This began by determining the exceedance fraction with regard to the censored data. Eight out of the 26 analytical samples were below the detection limit (DL) equaling a 31% censored data rate. The Environmental Protection Agency (EPA, 2006) offers the following recommended general guidelines, found in Table 7, for selecting a statistical analysis method at various margins of censored data. (US Environmental Protection Agency, 2006)

Table 7: EPA Recommended Methods for Censored Data

Approximate Percentage of Non-Detects	Statistical Analysis Method
< 15%	Replace non-detects with 0, DL/2, DL, Cohen's Method [MLE]
15% - 50%	Trimmed mean, Cohen's Method [MLE], Winsorized mean and standard deviation
>50%	Tests for proportions

Regarding the Cohen method based and the MLE method, the EPA clarifies, "Cohen's method provides adjusted estimates of the sample mean and standard deviation that accounts for data below the detection level. The adjusted estimates are based on the statistical technique of maximum likelihood estimation [MLE] of the mean and variance so that the non-detects are accounted for (US Environmental Protection Agency, 2006)."

The AFIT EAS provides the following five common methods for analyzing censored data: DL, DL/2, DL/$\sqrt{2}$, log-probit, and MLE. Because the SC censored data percentage was within the 15% to 50% range outlined by the EPA, the MLE method was chosen for the AFIT EAS, (based upon the work of Attfield and Hewett (Attfield, et al.,

1992; Hewett, et al., 2007). The MLE method derived the following parametric statics: GM, GSD, 95th percentile, and exceedance fraction.

The exceedance fraction for coal dust exposures for the task TWA was 56.7% with a GM of 0.5 mg/m^3, a GSD of 2.6 and the 95th percentile on the mean was 2.3 mg/m^3. The exceedance fraction for the 8-hour TWA during the sampling campaign was 11.0% with a corresponding GM of 0.1 mg/m^3, a GSD of 3.9, and with a 95th percentile on the mean of 0.7 mg/m^3. Exceedance fractions less than 5% or an upper 95th percentile less than the OEL are two common measures of an acceptably controlled exposure (Hewett, 2001). Based on these sample results, the exposure profile for this campaign is clearly unacceptable. An analysis of the exceedance fraction results of 56.7% and 11%, respectively, is interpreted as the percentage of the work force that are, on average, predicted to be overexposed on any given day. Therefore, EAS results that classify or predict an exposure profile as unacceptable, are considered correct to the true risk assessment categorization. The results summarized in Table 8 represent the statistical benchmarks by which all other EAS are compared.

Table 8: Analysis of the SC results using MLE method

	> Task TWA	> 8-hr TWA
GM (mg/m^3)	0.5	1.0
GSD	2.6	3.9
95th percentile on Mean (mg/m^3)	2.3	0.7
Exceedance Fraction (θ)	56.7%	11.0%

OSHA EAS Analysis

The OSHA EAS was evaluated by randomly selecting one 8-hour TWA from the available 26 sample events, repeated 10 times. Out of the 10 randomly selected sample

events, neither of the two potential overexposures was selected, corresponding to a 100% inaccurate acceptance of the exposure profile as controlled.

The AFIT EAS differed from the OSHA EAS in that DRI sampling was used in the first phase of the 10 rounds of random samples. Three out of the 10 rounds contained at least one 8-hour TWA overexposure in groups of three random sample events from the original 26 samples. With the added benefit of excursion limits, the AFIT EAS reached a 100% correct conclusion of uncontrolled exposure in the first phase of three DRI samples without proceeding to the final phase of integrated analytical sample collection. A summary of the 8-hour TWA results is found in Table 9.

Table 9: Comparison of the OSHA EAS to the AFIT EAS Using the 8-Hour TWA

	Analytical Results OSHA EAS > 8-hr TWA	Analytical Results AFIT EAS > 8-hr TWA
# over 0.4 mg/m^3	0 of 10	3 of 10
% Correctly Classified	0.0%	30.0%

A more general approach to the analysis of the OSHA EAS involves the question of the number of samples required, given a target confidence level and a known exceedance fraction. This is a generalized approach because the true exceedance fraction of a specific exposure profile is known only following a sampling campaign; however, the application of a minimal acceptable exceedance fraction can be established as a matter of policy. Regarding this research effort, the known exceedance fraction for the SC data was calculated to be 11% as shown in Table 8. Assuming that having 11% of an organization's work force overexposed on any given day is unacceptable, then how many samples would be required to have an 80% confidence that at least one sample is found over the 8-hour TWA? Figure 5 used the binomial distribution to illustrate that, on

average, 14 samples would be required to achieve an 80% confidence. This explains why out of 10 random samples, none were found over the limit.

Regarding the task TWA results, out of the same 10 randomly selected sample events, the OSHA EAS selected two task TWAs with concentrations that exceeded the TLV® out of a potential 16 over exposures. This corresponded to a non-parametric acceptance of 80% of the exposure profile incorrectly classified as controlled, even using the more stringent task TWA for the process duration rather than the 8-hour TWA.

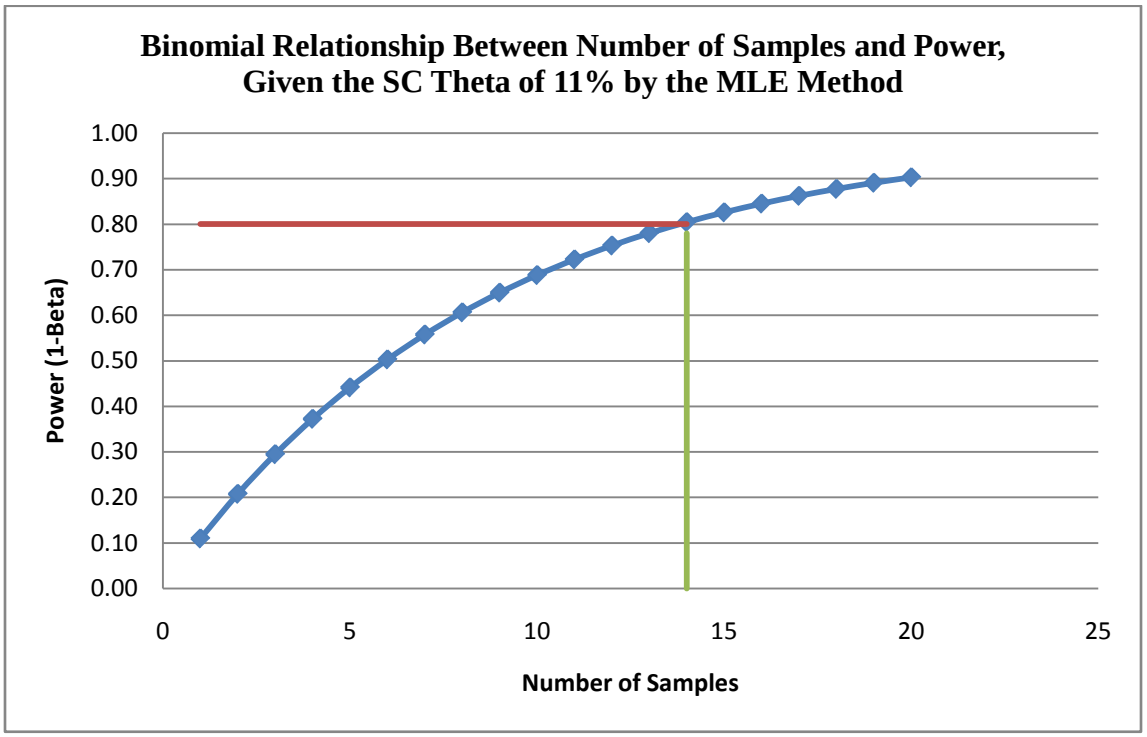

Figure 5: Binomial Distribution with 80% confidence and 11% Theta

The AFIT EAS selected at least one overexposure in the group of three random samples, 10 out of the 10 rounds when compared to the task TWA, resulting in a 100% correct classification. A summary of these results is found at Table 10.

Table 10: Comparison of the OSHA EAS to the AFIT EAS using the Task TLV®

	Analytical Results OSHA EAS > TLV®	Analytical Results AFIT EAS > TLV®
# over 0.4 mg/m^3	2 of 10	10 of 10
% Correctly Classified	20.0%	100.0%

A similar generalized parametric approach was used to evaluate the OSHA EAS with regard to the task TWA, which has a corresponding exceedance fraction of 56.7% as shown in Table 8. Figure 6 illustrates that an average of only two samples would be required to get one sample over the exposure limit with an 80% confidence.

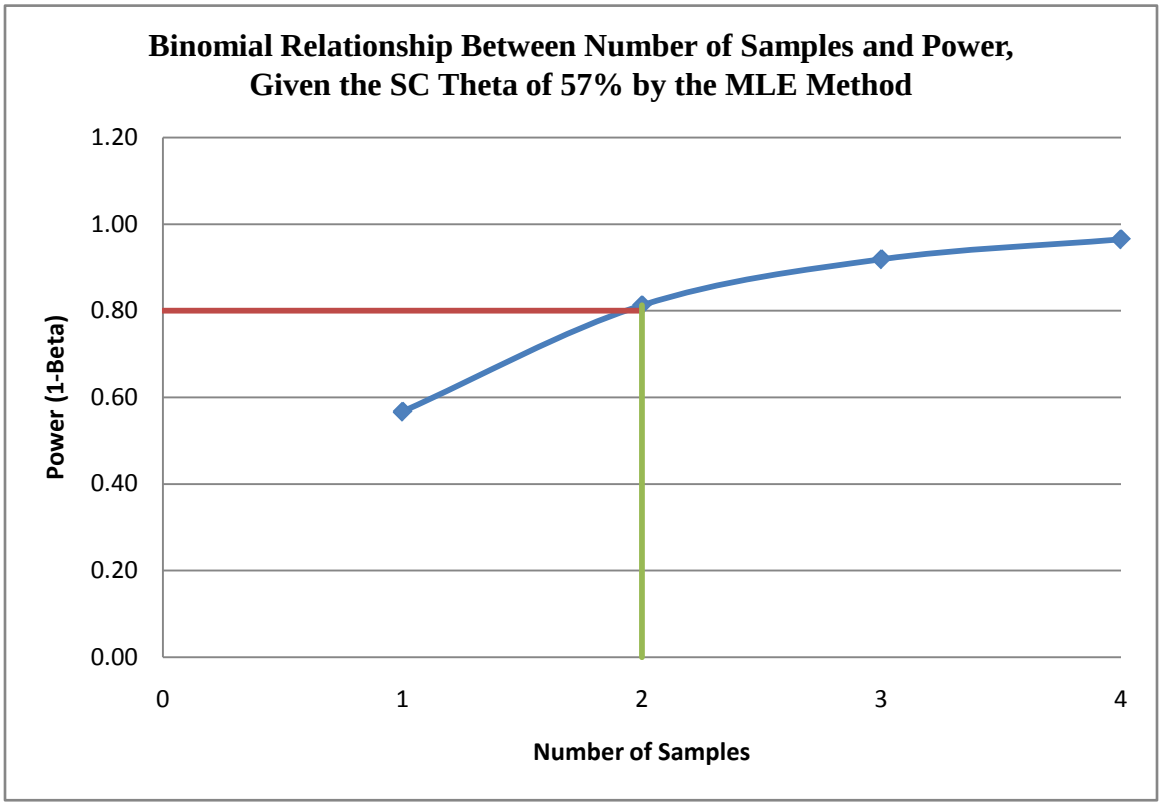

Figure 6: Binomial Distribution with 80% Confidence and 57% Theta

This shows that the OSHA EAS works reasonably well with extremely high exceedance fractions; however, for exposure profiles with significant yet relatively lower exceedance fractions the likelihood for detection drops dramatically. Alternatively, it implies that the

use of the 8-hour TWA for partial period samples could underestimate the risk assessment when using a compliance EAS.

Probability to Detect Overexposure Using Maximum Risk Exposure

The strength of the OSHA EAS lies in the central idea of selecting the maximum risk exposure, (MRE) often used synonymously with worst-case worker. The sample effort in this study only sampled the worst-case worker because only one worker performs this task. With only one worker to choose from, the worst day of exposure of the worse-case worker would classify the exposure as MRE. This is a subtle yet valid distinction to the method calculated earlier in this chapter of randomly picking from any of the 26 days of exposure.

The Venn diagram in Figure 7 below illustrates the general notion of an MRE. From the universal set of all possible sample results that can be evaluated (represented by the green background), the OSHA EAS is able to select only the worst-cases (regarding this study, only the worst-days) from which to sample (B). (B) is expressed as a percentage of the upper end of all sample results. Within (B) are the overexposures represented by (A). Regarding this study, (A) equals the two overexposures, therefore (A) is a subset of (B) as long as (B) is defined to be greater than two. Generally, a scenario exists that there could be more overexposures (A) than there are samples defined as worst-case for (B). To apply this general scenario, for which (A) is much larger than (B), to an actual work environment, would imply an exposure for which there is a clearly unacceptable exceedance of the occupational limit. In a case of this nature, the OSHA EAS method for validation of an obvious overexposure hypothesis may be well suited.

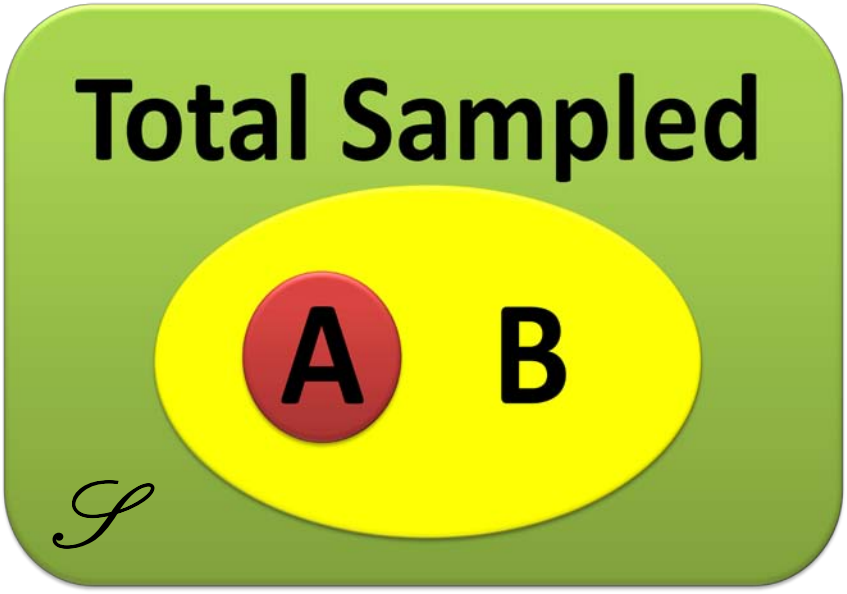

Figure 7: Venn diagram of MRE

In reference to the SC, the total number of samples collected is 26. Using the upper 30% as an assumed cut point for the worst cases of the sample distribution then (B) would equate to the eight highest exposure results. Of these eight worst cases, two were overexposures represented by (A). Therefore, the other 18 of the 26 samples would be defined as representative exposures, not "worst-case". Table 11, tabulates the statistical distinctions between these different sets of data.

Table 11: MRE Non-Parametric Probability

	B	B'	Total
A	2	0	2
A'	6	18	24
Total	8	18	26

The probability of (A) from the total samples is expressed as follows: P (A) = N (A)/N = 2/26 = 0.076. The probability of (B) from the total samples is expressed as follows: P (B) = N (B)/N = 8/26 = 0.308. Therefore, since (A) and (B) are not independent, the probability of (A) given (B) is expressed in equation 5 (Devore, 1987).

Equation 5: Proportion of Overexposure within Upper Third of Distribution

$$P(A|B) = \frac{P(A \cap B)}{P(B)} = \frac{(\frac{2}{26})}{(\frac{8}{26})} = 0.25$$

The variable (C) represents the likelihood that a technician is capable of selecting a worker-day from the worst-case portion of the distribution. Assuming 67% of the time a technician can sample in the upper 1/3 of the distribution (B), this accuracy is then designated as P(C) equaling 0.67. P(C) is independent of (A) or (B), therefore, the probability of collecting a sample from the overexposed portion of the distribution given the MRE is expressed in Equation 6 (Devore, 1987).

Equation 6: Probability of Overexposure Given MRE

$$P(D) = P\big((A|B) \cap C\big) = P\big((A|B) * P(C)\big) = 0.25 * 0.67 = 0.168$$

The analysis of the OSHA EAS worst-case scenario is that if an industrial hygiene technician was 67% accurate at selecting the upper 30% of the exposure distribution from a SEG with a non-parametric exceedance fraction of 0.076, they would have a 17% probability for correctly determining this exposure profile as uncontrolled using the assumption of the worst-case compliance method.

The general form of the probability equation using substitution between equation 5 and equation 6 is:

Equation 7: General Form of the Worst-Case Probability Equation

$$P(D) = P\big((A|B) * P(C)\big) = \left[\frac{P(A)}{P(B)}\right] P(C) = P(A)\left[\frac{P(C)}{P(B)}\right]$$

Equation 7, can be interpreted as the original exceedance fraction (A) multiplied by the chance of correctly sampling a "worst-cases" exposure (C), divided by the upper cutoff proportion of the distribution which defines "worst-case" (B).

Interestingly, if the capability to sample accurately the top half of the exposure profile were 50%, then the probability in equation 6 for P (D) would equal P (A) as seen below.

Equation 8: Probability Identity Theorem

$$P(D) = \left(\frac{(0.5)N(A)}{0.5N}\right) = \frac{N(A)}{N} = P(A)$$

Therefore, the notional benefits by using a worst-case sample method statistically diminish to equal that of a purely random sample with the limitations of intentionally biasing the data and thus invalidating the use of parametric statistical tools. Additionally, the false assumption is preserved that the results are more powerful than a purely random sample. This is due to the belief that an enhanced selection was made by sampling the worst-case worker on the worst-case day.

AIHA EAS Analysis

The AIHA EAS was evaluated with similar methods as the OSHA EAS, except instead of a single round of 10 randomly selected sample events, six rounds of randomly selected events were generated 10 times. Another distinction in the AIHA EAS is the evaluation of the upper 95th percentile for the group of six exposures, rather than the point estimate of a single exposure used by the OSHA EAS. The 95th percentile for the AIHA EAS exceeded the 8-hour TWA in six out of 10 random trials.

The AFIT EAS has the flexibility of using either the point estimate or the upper 95th percentile. When measuring exposure using the 95th percentile, the distinction between the AIHA EAS and the AFIT EAS comes down to a matter of the number and type of samples collected, six analytical opposed to three DRI, respectively. The accuracy of the AFIT EAS was calculated using three DRI samples randomly selected, replicated 10 times, in comparison to both the 8-hour TWA and the task TWA. The AFIT EAS resulted in five out of 10 trials, judging against the 8-hour TWA. However, when compared to the excursion limits specific to data logging capability of the DRI the AFIT EAS had a 100% classification of uncontrolled exposures.

Table 12: Comparison of the AIHA EAS to the AFIT EAS Using the 8-hour TWA

	Analytical Results AIHA EAS > 8-hr TWA	Analytical Results AFIT EAS > 8-hr TWA
# over 0.4 mg/m^3	6 of 10	5 of 10
% Correctly Classified	60.0%	50.0%

In reference to the task TWA results, out of the same 10 randomly selected groups of six samples, both the AIHA EAS and the AFIT EAS selected 10 task TWAs with 95th percentiles that exceeded the 8-hour TWA-TLV® out of a potential 16 over exposures. This corresponded to perfect categorization of 100% of the exposure profiles as uncontrolled. The only distinction was that the AFIT EAS took half as many samples to reach the same conclusion.

Table 13: Comparison of the AIHA EAS to the AFIT EAS Using the Task TLV®

	Analytical Results AIHA EAS > TLV®	Analytical Results AFIT EAS > TLV®
# over 0.4 mg/m^3	10 of 10	10 of 10
% Correctly Classified	100.0%	100.0%

An overall comparison of the EASs can be made by comparing the point estimates of the OSHA EAS (PT.) to the point estimate of the AFIT EAS (PT.) and the upper 95th percentile of the AIHA EAS $X_{0.95}$ to the AFIT EAS $X_{0.95}$. However, a true side-by-side comparison between all three cannot be made. Because multiple samples are required to calculate a geometric mean and geometric standard deviation with the purpose of deriving the upper 95th percentile as criteria for a decision, the fact that the OSHA EAS only uses one sample point prevents a three-way comparison.

Table 14: Side-by-Side Comparison using 8-hour TWA

	Sample Protocol	Results > 8-hr TWA
OSHA EAS PT.	1 Analytical	0 of 10
AFIT EAS PT.	3 DRI	3 of 10
AIHA EAS $X_{0.95}$	6 Analytical	6 of 10
AFIT EAS $X_{0.95}$	3 DRI	5 of 10

Table 15: Side-by-Side Comparison by Task TWA

	Sample Protocol	Results > TLV®
OSHA EAS PT.	1 Analytical	2 of 10
AFIT EAS PT.	3 DRI	10 of 10
AIHA EAS $X_{0.95}$	6 Analytical	10 of 10
AFIT EAS $X_{0.95}$	3 DRI	10 of 10

The AFIT EAS was more sensitive to detecting overexposures than the OSHA EAS, by a difference of 30%. When the sensitivity was based on the task TWA, the AFIT EAS was flawless in correctly classifying the exposure profile as unacceptable compared with only an accuracy of 20% for the OSHA EAS. AIHA EAS had a 10% greater sensitivity in detecting an overexposure than the AFIT EAS when compared to the 95th percentile. When the task TWA was used, both EAS proved 100% accurate. The distinction criteria between the AFIT EAS and the AIHA EAS was whether the AFIT

EAS could collect less samples than the AIHA while maintaining equal sensitivity and in every case, the AFIT EAS required half as many samples as the AIHA EAS.

Overall results yielded accuracies between 0 and 100% and between one and six samples collected. The AFIT EAS exemplified the best characteristics of an EAS by collecting only three samples while maintaining high sensitivity. While the AFIT EAS performed nearly flawlessly, there was however, areas of this study open to significant improvement. The next section will cover the most common limitations and anomalies, which challenged this research effort.

Limitations and Anomalies

During the course of the sampling campaign, a variety of irregularities in the data collection arose. This section describes those anomalies and the action taken to account for their impact and a description of the limitation this caused.

One error occurred on the 26 Dec 2008 sample at Bldg 770 at the Area B heat plant. The DataRAM® lost power at 0755 hours and a new battery was installed at 0820 hours, resulting in 25 of 141 data points lost. The exposure concentration at the time of the power failure was 0.262 mg/m^3 and upon return, the exposure was 0.272 mg/m^3. The average exposure based on the analytical sample, which continued to be collected, was a concentration of 3.71 mg/m^3. Therefore, since both figures were well below the average concentration, the 0.262 mg/m^3 was applied to the lost DataRAM® measurements. This had very little overall impact because all DRI samples, in general, were adjusted based on the analytical sample results and both are represented in the sample graphs found in Appendix C: Exposure Assessment Graphs.

This same sample event had a related error in the exposure duration resulting in an error in the air volume reported for the sample number SZ089012. The reported air volume was 481.68 liters, while the true volume was 377.32 liters. The average concentration was reported as 2.9 mg/m^3, from a mass of 1.400 mg by Bureau Veritas. However, when the true air volume is used, 1.4 mg/0.37732 m^3 equates to a corrected concentration of 3.71 mg/m^3.

There were several occasions where the WBGT was not operational for the entire sampling event, by either starting late or ending prematurely. When relative humidity data was lost, a value of 0.01 was used which mathematically preserves the original data. Eleven days had between 1 and 8 minutes of lost data. A detailed tabulation of the days and minutes lost can be found at Table D6 at Appendix D: Tabulated Sample Data. The impact of this was minimal due to the use of the analytical data as the ultimate correction factor.

There were two occasions were the GilAir5® failed. Unlike when the DataRAM® failed and the gap in logged data was clearly evident, the loss of airflow in the sampling train can be seen by a drop to background concentration levels in the DRI. The first occasion was the result of tampering with the pump from the test subject. It occurred at approximately, 0812 hours on 31 Dec 2008 at the Area B heat plant. The pump was restarted at 0834 hours, resulting in a loss of 22 minutes of sample data. The exposure concentration at the time of the pump failure was 0.155 mg/m^3 and upon return the exposure was 0.107 mg/m^3; however, according to the analytical sample the average exposure concentration was 0.498 mg/m^3. Therefore, since both figures were below the average concentration, a value of 0.1 mg/m^3 was applied to the lost DataRAM®

measurements. The benefit to using 0.1 mg/m^3 is that it is representative of a conservative background level rather than using zero, which is unrealistic. Using a representative value for the DRI sample makes the correction factor when applied to the analytical samples more comparable.

The other occurrence of a GilAir5® pump failure was on 2 Jan 2009 at the Area B heat plant. The cause of the pump failures was due to three occasions of the sample hose crimping when the test subject sat in a chair. This was the most challenging of the anomalies for which to account due to the uncertainty as to when the pump went from a restricted flow to a complete pump failure. Review of synchronized video footage could not identify pump failure; therefore, to maintain consistency, the value of 0.1 mg/m^3 was again applied to the 42 minutes of missing data.

V. Conclusions and Future Research Considerations

Chapter Overview

Chapter V provides a discussion on the survey results and analysis as related to the original research objectives. Furthermore, an assessment of the strengths and limitations is presented, leading to suggested methodology improvements. This chapter concludes with recommendations for future research.

Research Summary

The primary purpose of this research effort was to answer the research questions posed in Chapter I. These questions were related to the accuracy and efficiency of the AFIT EAS in comparison to the OSHA EAS and the AIHA EAS when tested against an actual sample campaign.

The first question was, "Does the AFIT EAS result in a correct risk assessment outcome more often than the OSHA EAS?" It was shown in Chapter IV that the AFIT EAS reached the correct risk assessment outcome 30% of the time compared to the OSHA EAS of a 0% success rate, when judged against the 8-hour TLV®-TWA. Through further binomial testing, the OSHA EAS required, on average, 14 individual sampling events to detect just one overexposure with 80% confidence at the SC exceedance fraction of 11%. However, both strategies improved when judged against the task TWA. The success rate of the OSHA EAS rose to 20% while the AFIT EAS rose to 100%. The OSHA EAS also saw improvement in the average number of samples required to detect

one overexposure from 14 down to two. Nevertheless, in every instance the AFIT EAS proved more sensitive to overexposures than the OSHA EAS.

The second research question was, "Does the AFIT EAS reach the correct risk assessment outcome using fewer integrated samples than the AIHA model?" Results showed that the AIHA EAS was able to reach a 60% success rate in assessing risk when compared to the 8-hour TWA through the collection of six integrated samples. The AIHA EAS improved to 100% when compared to the task TWA. However, the AFIT EAS was able to reach a 100% conclusion in both categories through the analysis of three DRI results validated by three integrated samples. Therefore, in every instance, the AFIT EAS collected half as many samples while resulting in a 100% success rate in hazard characterization.

The third research question is more subjective than the first two, "What benefits (if any) does the AFIT EAS bring in addition to relative increased accuracy and fewer samples?" Overwhelmingly, the AFIT EAS encourages the use and mastery of DRI. Due to their rapid return of results, DRIs allow for the intervention of control strategies on the spot. Being able to rapidly and accurately characterize a hazard and implement a mitigating control is extremely valuable in garrison, but even more so during a contingency or deployed environment when waiting weeks for an analytical lab is not feasible. Instituting regular usage of DRIs builds confidence and expertise in the correct function of the equipment and gives familiarity to the specific limitations. The additional insight gained though the use of an EA time history graph can clearly give distinction to the determinants of exposure as well as nodes of control. For example, Figure 4 "Visual

Characterization of 1-Minute Average Concentration Results" from Chapter IV is reproduced here with the addition of a corresponding exposure characterization.

The regions of the graph circled in green correspond to occasions when the worker left the bunker area to check a grate which filters chunks of coal too large for the furnace. The location of the grate is where the coal enters the plant from an outside conveyor belt, which is partially open to the outside air. This clearly corresponds to the lowest exposure levels during the shift. Traditional analytical air sampling is typically motivated by a desire to find incidences of high exposure; conversely, excessively low exposures are undesirable due to the potential for a non-detect value. With regard to DRIs, low exposures have the benefit of providing "nodes of localized control". These control nodes can be evaluated and exploited, by asking, "How can these low exposures be increased in frequency or duration?" and "Can the behavior which lead to this short term control of exposure be encouraged through training or other means?" What was a potential limitation for the analytical method, becomes a strength when using the DRI.

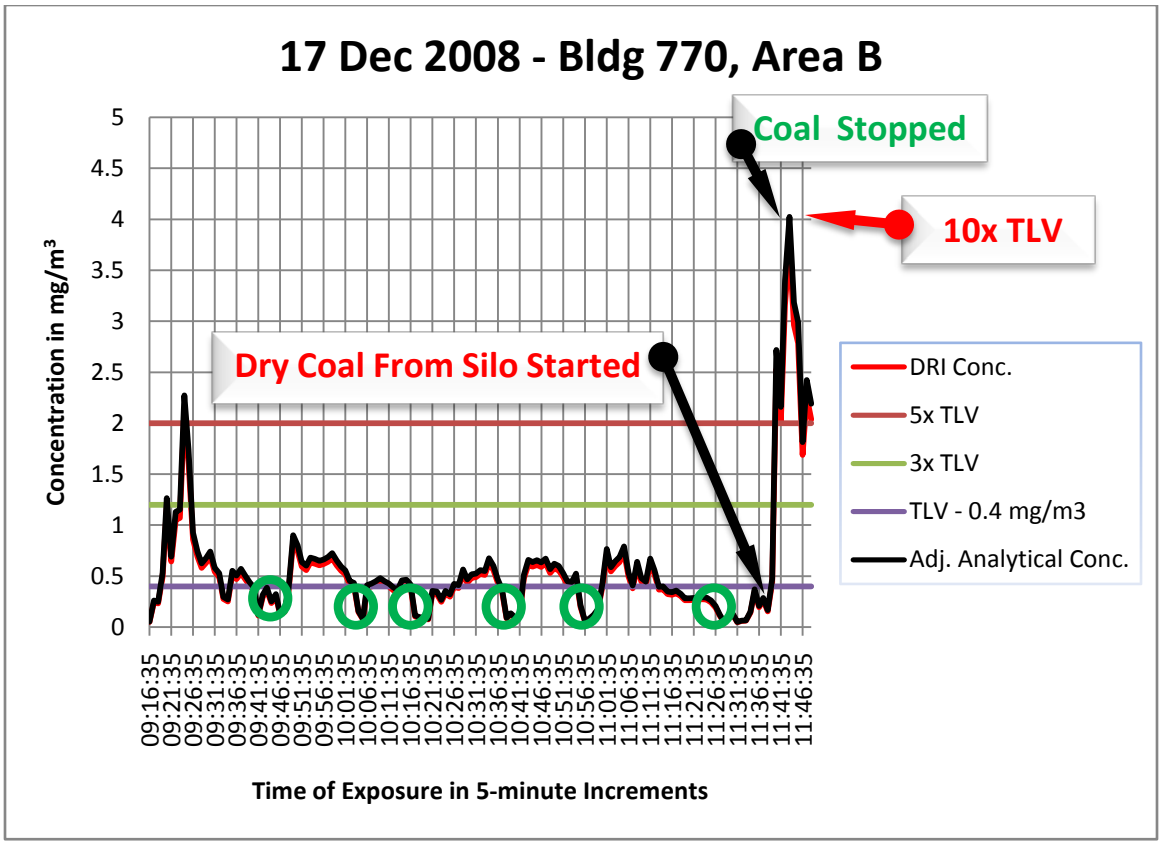

Figure 8: Hazard Characterization and Interpretation

Concerning the graph once more, the opposite extreme to control nodes is excursions well above the TLV®. An arrow at the base of the steep peak at the right of the graph marks the initial insult of coal dust on the work environment. This rise to 10 times the exposure limit corresponds to the introduction of the dustier coal from the storage silo. Through a simple visual assessment of the graph, the introduction of silo coal can easily be characterized as the most significant determinant of exposure that day.

This exposure graph can also be used as an educational tool for the worker to see the relative hazards for each sub-activity within their specific task. The ability to quickly generate this graph allows the worker to more easily remember the specific exposures that are illustrated. If the use of PPE were in question, this graphical representation of the potential hazardous environment can serve to reinforce the need for proper and consistent

PPE usage. In general, even with only one sample, the DRI allows for a more complete understanding of exposure for both the industrial hygienist and the exposed workers.

In summary of research question three, the information gained from the AFIT EAS and even one DRI sample is much more robust and insightful than could possibly be gained by the data provided by several analytical samples. To underscore this point, the corresponding 8-hour TWA for the exposure discussed above was 0.189 mg/m^3, which is less than half the 8-hour TLV®-TWA of 0.4 mg/m^3. Therefore, under current guidance, this exposure would be incorrectly classified as a well-controlled exposure, requiring no follow-up sampling, no medical monitoring, no additional education and no controls of any kind.

The last research questions was, "What limitations (if any) does the AFIT EAS have which fails to outperform either the OSHA or AIHA EAS?" While the AFIT EAS is by no means perfect and still requires further testing, this study did not find any relative weaknesses when related to either the OSHA EAS or the AIHA EAS. However, the next sections of this chapter will focus on areas for improvement and limitations of both this study and the AFIT EAS.

Suggested Methodology Improvements

The use of an optical particle counter would have given better insight into the size distribution of the dust allowing for a more precise calculation of the DRI correction factor as related to the analytical data. (O'Shaughnessy, et al., 2002) A more reliable conversion between the DRI and analytical results could preclude the analytical component, saving time and money.

Strengths and Limitations

Strengths and limitations are common to every study and unique to each particular research effort. However, by acknowledging these perceived successes and failures, future researchers are provided with an awareness of the common pitfalls and a foundation with which to develop deeper understanding and discover fresh innovations.

Strengths

The most profound strength was the power and insight of the exposure assessment graphs. If a picture is worth a thousand words, then a graph of the exposures is worth a hundred analytical samples. This point was addressed at length in the section above titled "Research Summary" within this chapter.

Another key strength was the use of parametric and non-parametric statistics in the comparison of the EASs. The calculation of the probability function describing the likelihood for a worst-case exposure assessment to identify successfully an overexposure was of particular interest. By defining three variables, 1) the accuracy of a technician's ability select a worst-case worker, 2) the percentage of the exposure distribution defined as worst-case, and 3) the exceedance fraction of the exposure profile, then the probability of sampling an overexposure can be calculated.

With this probability function, various scenarios can be tried by modifying the three components, to see the value and limitations of the worst-case model. One of the limitations discovered was that under certain conditions, the probability for finding an overexposure using the worst-case method, regardless of the exceedance fraction, would statistically equate to the probability of using a purely random sample. For example, if the top half of the exposure profile defines the worst-case and the technician has only an

accuracy of 50% for selecting a worst-case exposure, the probabilities for the worst-case method are no better than the random sample method. Note that while the probabilities are equal, the statistical benefits to random sampling are lost in the case of worst-case sampling due to the intentional biasing of the data.

Limitations

In addition to recognizing a study's strengths, it is equally important to document and analyze a study's limitations. With respect to this research effort, specific limitations regarding data collection and analysis have previously been addressed in earlier chapters. However, there are general limitations to the research at large as well as isolated observations requiring further critique.

An argument can be made that the use of DRIs by the AFIT EAS presents a limitation in accuracy, compared to an analytical method. DRIs have limitations with inaccuracy and inconsistency under certain field conditions. For example, research indicates that certain field portable organic vapor DRIs perform inconsistently under high humidity conditions and are not recommended for compliance sampling with OELs. (Coffey, et al., 2009). Specifically, the DataRAM® used in this research also over responds to humidity levels exponentially above 60% relative humidity. (Chakrabarti, et al., 2004) Each DRI has specific limitations, which must be taken into account. For instance, relative humidity in this study was recorded and results were adjusted accordingly. The key to the AFIT EAS is through frequent field-use an increased familiarity with the available inventory of DRIs will allow for the management of these shortcomings under non-life threatening circumstances. In addition, for comprehensive

EA, it is better to have a large number of slightly less accurate sample data than a single highly accurate sample point taken over the same period.

Another limitation is in reference to the exposure assessment. The sampling campaign's coal exposure results as described by the exposure profile were determined to be uncontrolled. Therefore, the field evaluation was one sided in that it could only test the ability of a strategy to reach a positive conclusion toward an uncontrolled exposure conclusion. This potentially favors EAS, which are more sensitive to the beta error without evaluating their potential insensitivity to the alpha error. The question left unanswered is, "What is the risk that an exposure will be found unacceptable when in truth it is acceptable? It is important to note that the EAS does not have a causative effect on exposure. They are simply tools for evaluating what is already the true workplace exposure. Therefore, if there are no overexposures during sampling, an EAS, which is extremely sensitive toward detecting overexposures, will not find what is not there. The problem does present itself when a relatively low exceedance fraction is determined to be adequate. However, this limitation is not necessarily on the part of the discovery of overexposures but in the lack of guidance as to what exceedance fraction is acceptable.

The lack of guidance regarding the exceedance fraction is the last limitation covered in this section. This limitation is not specific to the AFIT EAS but is a concern for all comprehensive exposure assessment models involving the notion of the exceedance fraction. The idea that a certain percentage of the population is perpetually at risk for exceeding the exposure limit is unsettling. Furthermore, the proposal of formally establishing an acceptable exceedance fraction that workers are allowed to be overexposed to is intuitively objectionable. However, the realization that the work force

is statistically overexposed at a given percentage is the foundation and justification for the existence of the entire occupational health and safety industry. By not defining a reasonable exceedance fraction, in effect the hierarchy concurrently accepts and rejects all exceedance fractions. The impartial application of the AFIT EAS is hindered by the absence of a clearly defined acceptable exceedance fraction. The open interpretation of an acceptable exceedance fraction, predictably allows that some will not tolerate even a 1% exceedance while there will be others who will not act upon 25% or even higher exceedance fractions. The recommendation of an acceptable exceedance fraction is outside the scope of this research effort. A study of the benefits and limitations of various levels of exceedance is worthy of future research.

Recommendations for Future Research

However, the need for further research and study is not limited to the topic of the exceedance fractions. The potential approaches to future research fall into two categories: the expansion of this study and the development of related research areas. Recommendations for future research are plentiful in both categories.

Expansion of This Study

This study is naturally divided in to two endeavors, namely, the sample collection effort and the EAS evaluation effort. Each of these phases of the study can be expanded in their own right.

With respect to the data collection campaign, a companion study using a vapor or gas exposure would provide the opportunity to use all three tiers of the AFIT EAS. Additionally, there are other classes of DRIs available to the AFIT EAS to incorporate using a gas or vapor contaminant.

As mentioned in the limitations section, an exposure assessment with a lower exceedance fraction could be conducted. However, this presents the problem of increased analytical samples that fall below the limit of detection.

With regard to the EAS evaluation phase, additional EAS strategies used in industry could be challenged using the existing sample data from this study. The AFIT EAS was anticipated to be significantly distinct from both the OSHA and AIHA models. However, there are lesser-known strategies that could be incorporated into the AFIT EAS for a more refined model.

Additional Research Areas

Opportunities for future research also exist in related areas of study outside the scope of this research initiative. Additional research in the use of Bayesian statistics would facilitate the comparison of the data and results in relation to exposure categorization, control banding, and professional judgment. (Hewett, et al., 2006) Currently, the Air Force categorizes shops into one of three risk categories. However, the use of Bayesian statistics would not only categorize the exposure but also facilitate the categorization of the professional judgment component associated with the final assessment.

Conclusions

Without question, a formal strategy for the Bioenvironmental Engineering career field is necessary. The Bioenvironmental Engineering vision statement is, “Optimize combat capabilities by preventing casualties and enhancing performance in the deployed and in garrison environments through full spectrum threat health risk reduction”(USAF, 2006) The AFIT EAS directly supports this vision as it prevents casualties and enhances

performance by more accurately detecting overexposure than traditional AF methods. In addition, the AFIT EAS aids in the development of a "full spectrum threat health risk reduction" by encouraging the everyday use of DRIs.

Likewise, the mission statement is, "Provide operational health risk assessment expertise to enhance commander decision making and health service support capabilities". The AFIT EAS also supports the mission statement as it gives commanders and BEEs a more robust understanding of the health risks faced by our fellow Airmen.

Regardless of whether the AFIT EAS is ever adopted as official doctrine, every worker in our Air Force deserves a comprehensive health risk assessment for expert risk management. Mulhausen phrases it best with his quote,

> "Because a comprehensive approach to exposure assessment provides a more complete understanding of exposures than the compliance approach, it enables better management of occupational hygiene-related risks. It helps provide assurance to an organization's management, customers, employees, and the communities in which the organization operates that occupational health risks are understood and that the proper steps are being taken to manage the risks." (Mulhausen, et al., 2003)

It is due to the congruency of a comprehensive approach with the vision and mission statements the next step in excellence in health assessments should include this strategy.

Appendix A: AFIT EAS

The following is the AFIT EAS student project reprinted in its entirety.

Inhalation Exposure Assessment Strategy

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Disclaimer: "The views expressed in this article are those of the authors and do not necessarily reflect the official policy or position of the Air Force, the Department of Defense or the U.S. Government."

Contents

Introduction

The United States Air Force (USAF) Bioenvironmental Engineers (BEE) have traditionally relied on a few air samples combined with professional judgment to estimate inhalation health hazards in AF industrial work centers. However, due to large variability within and between workers, small sample sizes may underestimate the true exposure; thus unknowingly placing AF workers at risk to inhalation hazards. This study proposes an improved exposure assessment (EA) model that will increase confidence in exposure characterization, build technical experience with direct reading instruments, and ultimately provide better protection for AF industrial workers, all without a significant increase in the BEE's workload.

Background

Base level BEEs often rely on an inspector type sampling regimen for assessing an employee's risk to inhalation hazards. Sample size is often limited to one or two integrated samples. Health risk decisions are based on the upper confidence limit of the sample and considered an acceptable exposure if it is below the occupational exposure limit (OEL).

In order to understand why this compliance type approach to an EA may introduce excessive employee health risk, an understanding of an exposure profile is required. Most workplace exposure profiles may be approximated as a log-normal distribution because the majority of the exposures will be at the low end of the distribution, with an extended tail at the higher end of exposures (NIOSH, 1977; NIOSH, 1976). The distribution is bounded on the left side of the curve by zero because measured exposures cannot be less than zero. On the right side, the distribution is capable of orders of magnitude in difference. The advantage of

describing the exposure profile with a log-normal distribution is that parametric statistics can be applied. The distribution is described by a geometric mean (GM) and a geometric standard deviation (GSD). The data could be transformed by taking the log of the data points to get a normal distribution with a standard mean and standard deviation which enables the use of traditional statistical analysis. While the GM is important in determining the exposure profile, understanding how the GSD affects the exposure profile is vital to understanding how low sample numbers can drastically mislead the decision maker. As the GSD increases, the curve will spread out along the x-axis creating a longer tail while expressing increased variability in the exposure (Fig 1). Illustrated below are log-normal distributions all with a GM of 0.5 yet with four different GSD's. With a GSD of 1.5, most of the samples taken will fall near the GM of 0.5, and quickly decreases after 1. In contrast, with a GSD of 4.0, the majority of the samples are near 0.1, and the tail spreads much further. This means in a highly variable process (those with a large GSD), the majority of the samples taken will be at the low end, and overexposures are more easily missed.

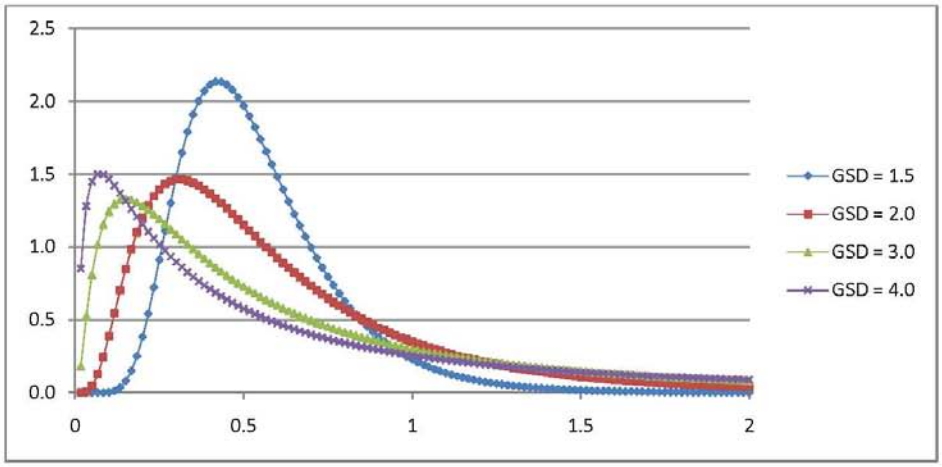

Figure 1: Effect of GSD on Log-Normal Distribution with GM=0.5

2

Typical ranges of GSDs within the AF industrial processes have been difficult to determine due to lack of data and imprecise records (Decamp, 2008). However, in a 1976 NIOSH technical report, 59 GSDs from various industrial processes were calculated from multiple sampling events performed on each of the processes. The results showed that the GSDs were frequently above 2.0, and as high as 3.1. The study introduced the idea that "higher GSDs require lower fractional action levels" (NIOSH, 1976), suggesting a process with a GSD of 2.0 would require an action level of 0.115 times the OEL to ensure no more than 5% of the employees' exposures exceeded the OEL.

In order to gain additional understanding on how low sampling numbers can lead to poor decision making when the measured process has a log-normal exposure profile, a log-normal curve was generated in an Excel® spreadsheet (Microsoft Inc., Bellevue, WA) with a GM=0.5 and a GSD=2.5 (Fig 2). The OEL for this profile is 1.0. Examining the cumulative density function (CDF) of this graph (read from the right side of the scale), 78% of the exposures are below the OEL leaving 22% of the exposures above the OEL. Therefore, there is a 78% chance of finding that the exposure is compliant based on the simple compliance strategy interpretation of the data. Additionally, approximately 50% of the daily exposures will be below the typical Air Force action level of half the OEL. This implies that there is a 50% likelihood that a processes-based, exposure assessment of one "screening" sample would yield a determination that no follow-up action of any kind is necessary; when in truth over 1 in 5 employees are routinely being over exposed.

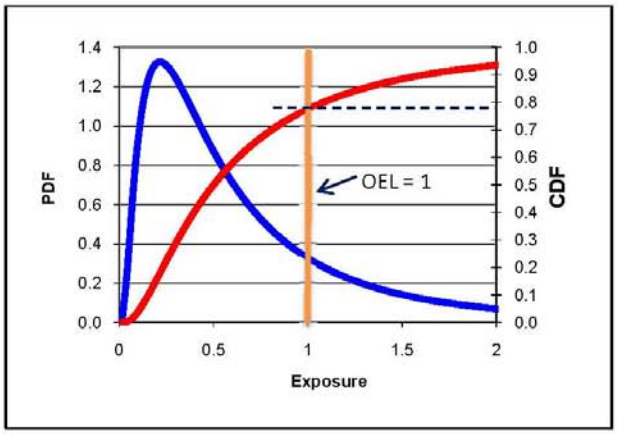

Figure 2: Example of log-normal distribution

One strategy to reduce the employee's risk of overexposure would be to implement control measures at a designated level below the OEL; however, this could lead to a waste of resources by controlling an increased percentage of processes that do not require controls. The preferred solution is to develop a strategy, such as the one proposed in this report, which increases exposure characterization confidence without significantly increasing the BEE's workload.

The goal of an exposure assessment sampling strategy is to limit needless expenditure of resources toward controlling low risk processes while, simultaneously, making informed risk decisions that ensure processes that may expose employees to health hazards are identified for mitigation. In statistical terms, this concept is divided into two competing goals. The first is the commanders' risk in expense (α error) when processes are needlessly controlled and the second is the employees' risk of illness (β error) when processes are not controlled when needed (Table 1).

Table 1: Alpha and Beta error

Decision	True Exposure Profile	
	Acceptable	Unacceptable
Unacceptable	Commander's Risk ($$) (α)	Power ($1-\beta$)
Acceptable	1-Commander's Risk ($1-\alpha$)	Airmen's Risk (Illness) (β)

Performance curves can be developed from the available freeware *Exposure Assessment Strategy Simulator* (http://www.oesh.com) to understand the error associated with various exposure strategies. The performance curves are generated utilizing a random number generator and a user defined GM and GSD (Hewett, 2005). The performance curve is then used as the true exposure profile in order to estimate the error associated with a particular sampling protocol. Note that in reality, the true exposure profile can never be fully known, while sampling gives only an approximation of the exposure profile.

To judge the adequacy of an exposure profile, the employer must have clearly defined the acceptable threshold levels for the alpha error, the beta error and the exceedance fraction, as well as a realistic sample size (Table 2) (Hewett, 2005). The exceedance fraction is the percentage for which an overexposure would be allowed throughout the workforce. Literally, it is the percentage of the workforce which is expected to exceed an established fraction of the OEL. For purposes of this illustration, we define a clearly acceptable exposure as ½ the OEL, meaning that no control measures will be implemented if the measured exposure is ½ the OEL. We define an unacceptable exposure as >5% of the employees may be above the OEL at any one time. An equivalent but reciprocal view of the 5% exceedance fraction is to look at the group 95th percentile, meaning 19 out of 20 workers are at or below the OEL at any one time.

Table 2: Performance Curve Variables

Variable	Description	Implications of Decision
Exceedance fraction	The fraction of the workforce's exposures that exceed an exposure limit	A low exceedance fraction (1%) is very difficult to prove with any degree of confidence, while a high exceedance fraction (25%) can be achieved with a high level of accuracy, worker risk is too high
α error	The probability that a clearly acceptable exposure will be declared unacceptable Note: α error is dependent on defined exceedance fraction	Low α error means processes are not over-controlled, but employee risk may increase as α error decreases. As α error increases, the risk to the commander increases in the form of overspending on control measures
β error	The probability that a clearly unacceptable exposure will be declared acceptable Note: β error is dependent on defined exceedance fraction	Low β error means low risk to the employee of being overexposed. As β error increases, the risk of not controlling an overexposure increases.
Power (1-β)	The confidence the decision maker has that the exposure does not exceed the established exceedance fraction	The higher the power, the greater confidence one has that the exposure is either clearly acceptable or clearly unacceptable based on the established exceedance fraction
Sample size	The number of full period, time weighted average samples	Increasing sample size can decrease α and β error, but limited funds and resources will dictate practical sample sizes

Figure 3 shows an example performance curve for a group 95th percentile exposure with an OEL of 1. The blue line in the graph represents the true exposure profile and the red line represents the average number of samples. From the graph, the β error is estimated at 12%. This means that 12% of the time the exposure will be incorrectly considered acceptable. Looking at the power (1-β), the BEE can be 88% confident no more than 5% of the employees are above the OEL at any given time. This represents a fairly good confidence in the exposure profile. In contrast to the low β error, the α error is fairly high at 40% when using an action level of ½ of the OEL, meaning 40% of the time an exposure will be controlled unnecessarily. The BEE is only 60% confident that the process needs to be controlled to ensure that no more than 5% of the

workers will be overexposed. This is an example of low risk to the employee, but high risk to the employer. Again, the goal of the sampling strategy is to minimize both the alpha and beta errors while maintaining a low sample number.

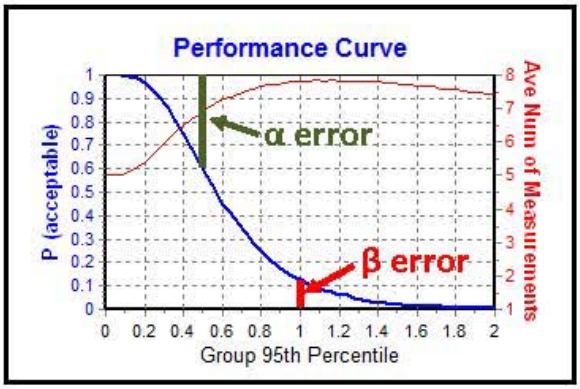

Figure 3: Example Performance Curve (GSD=1.5)

In order to estimate the alpha and beta error with current BEE sampling protocols, we investigated performance curves with a GSD of 2.5. The GSD of 2.5 was chosen as the mid-range of GSDs from the 1976 NIOSH study (NIOSH, 1976). A GSD greater than 2.5 may indicate that the similar exposure group (SEG) is not well defined. A sample size of 1, 3, and 6 was invested for the 90th percentile (1 out of 10 workers may be overexposed) using a compliance type strategy where each exposure measurement is compared directly to the OEL.

Figure 4 shows the group 95th percentile performance curves for sample sizes of n=1, 3, and 6 using the OSHA strategy of comparing each exposure to the OEL and with an action level of 50% of the OEL. With n=1, the BEE can only be 5% confident (1-β) that no more than 5% of the employees (95th percentile) are overexposed at any given time (Figure 4A). Confidence increases with sample size. With n=3 and n=6, the confidence is 15% and 25% respectively (Figure 4B-4C). The α error is acceptable in all cases, with a 99%, 98%, and 97% confidence

that when the BEE states a process needs to be controlled, that the process does indeed need to be controlled. The low α error is simply a reflection of how seldom a process will be found out of compliance. Obviously, base level BEEs need greater confidence in exposure assessment to make informed decisions about exposure control. Of note, AF processes may have a much higher GSD than 2.5 creating even higher β errors than illustrated in this example.

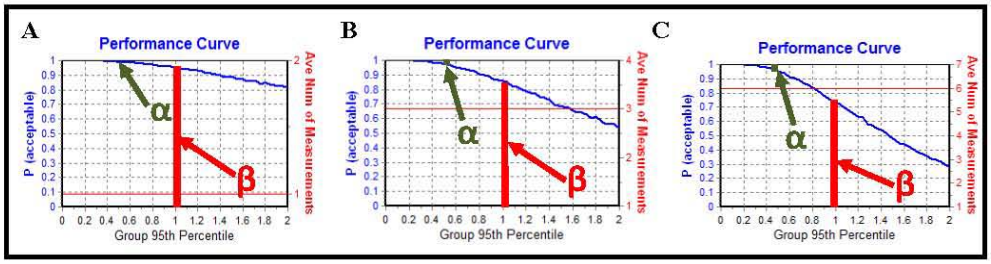

Figure 4: OSHA performance curves for 95th percentile (GSD of 2.5)

Often considered the standard model for a good exposure assessment, the American Industrial Hygiene Association (AIHA) EA states to collect six to ten random samples and compare the upper percentile of the samples is estimated and compared to the OEL. Figure 5 below is the performance curve for the AIHA strategy for a GSD of 2.5 and n=6. The difference AIHA method (Fig 5) as compared to the OSHA method (Fig 4C) is the AIHA method compares the upper percentile to the OEL, rather than each individual measurement as with the OSHA method. The beta error with the AIHA method is still fairly high, having only a 45% confidence the 95th percentile is below the OEL (the β error shows 55% of the time the exposure will be judged acceptable when in reality the 5% of the exposures can e expected to be above the OEL). While an improvement the OSHA method, the AIHA method may not offer sufficient confidence to make control decisions. As mentioned earlier, increasing the sample size will increase confidence in the characterization; however, large sample sizes may not be practical with the

limited resources available to the BEE. Therefore, the proposed strategy demonstrates how confidence can be gained without significantly increasing the sample size.

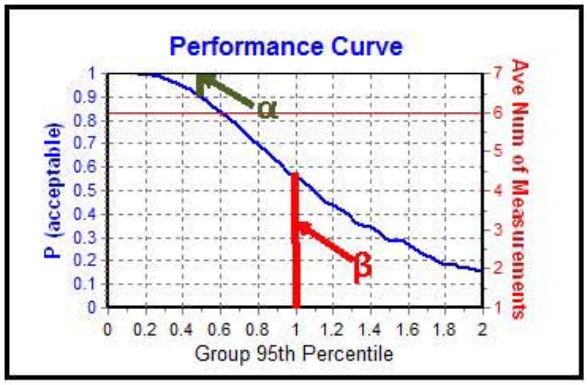

Figure 5: AIHA performance curve for the 95th percentile

Methods

The proposed sampling strategy utilizes a tiered approach. Tier 1 employs gas and vapor airborne concentration modeling to determine if an overexposure is possible based on the amount of material used in the process, the room dimensions where the process is performed, and the type of ventilation used for the process. The modeling can be used to show the exposure is clearly acceptable because an overexposure is physically not possible. For exposures found to be clearly acceptable no further characterization is required and a health risk assessment can be made without direct or integrated sampling. However, modeling should not be used to determine an actual exposure. When modeling cannot rule out an overexposure, tier 2 implements direct read instruments (DRIs). The DRIs can be used to estimate an airborne exposure. Thus, DRIs can demonstrate that an exposure is clearly acceptable or clearly unacceptable. When the exposures do not fit into the clearly acceptable or clearly unacceptable categories, then the final tier utilizes traditional integrated sampling to fully characterize the exposure.

Modeling

Modeling can be a quick method to determine if, due to exposure conditions, a gas or vapor overexposure is physically not possible, thus, reducing the amount of air sampling required while increasing confidence in the exposure assessment. As with the overall EA strategy, modeling is performed stepwise, starting with the simplest, most conservative models and moving to more complex models if needed. The first step is the saturation model. This model assumes the chemical's saturation point is reached (the maximum possible concentration based on the chemical's vapor pressure). The saturation model does not take into account the amount of material present and assumes saturation is reached and inhaled for the full work shift. If the saturation model shows a possible overexposure, the next step is to determine if enough material is present to reach saturation, this can be considered "worst case" model because it assumes the entire quantity of the chemical used in the process is inhaled. If the "worst case" model still estimates an overexposure is possible, it is necessary to move to the last model, the general dilution model. This model is more complex and takes into account generation rate and dilution ventilation (Milz, Conrad, & Soule, 2003). The compilation model incorporating each step was developed in an Excel® spreadsheet (Microsoft Inc., Bellevue, WA) and is included as an electronic attachment at attachment 2.

Air Sampling

As mentioned earlier, the employer must first decide what a clearly unacceptable employee exposure is and what a clearly acceptable exposure is in order to develop an exposure assessment sampling strategy. We investigated three possible exceedance fractions, less than 1%, 5%, and 10%. For each exceedance fraction, we looked at 90^{th}, 75^{th}, and 50^{th} percent confidence limits. Each case was investigated to find the minimum number of samples required

to obtain the necessary confidence level. According to NIOSH, a measurement is considered acceptable if it has an accuracy of the method is: ± 25% if above the OEL, ± 35% if above between the action limit and the OEL or ± 50% if less than the action limit (NIOSH, 1977). Therefore, our sampling plan integrates DRIs into the EA. Initial sampling uses DRIs when the exposure being measured can be quantified with a DRI. If a DRI is used in the exposure assessment and the exposure was clearly acceptable or clearly unacceptable, sampling stops and a health risk assessment is made. If the DRI measurement did not clearly determine an acceptable or unacceptable exposure, then integrated sampling would need to be accomplished. The modeling spreadsheet at attachment 2 includes methods to develop an 8-hour TWA using direct read instruments following NIOSH method 77-173.

Education Plan

The intention of this study is to introduce a new concept to exposure assessment within the AF. This cannot take place within an education plan for the entire BEE and BEE technician career fields. All personnel within the career field should have been introduced to the log-normal distribution concept through the web-based training required to receive a DOEHRS log-in (https://mhslearn.csd.disa.mil/ilearn/en/learner/mhs/portal/home.jsp). We recommend as an initial step for all personnel to review the training slides by searching "DOEHRS" at the mhslearn.csd.disa.mil training portal. Further training could be accomplished through a variety of methods including, USAFSAM, webcasts, or PAT distribution.

Results

A working spreadsheet for modeling is included in this EA strategy. A front page was developed for the spreadsheet in order to simplify user input. Each modeling step can be viewed

and printed for documentation purposes. Specific instructions for the use of the modeling software are included in the spreadsheet.

The air sampling strategy simulations proved that achieving a 1% exceedance fraction would be very difficult to achieve with any degree of confidence. In contrast, the 10% exceedance fraction could be achieved with a limited number of samples (table 3).

Table 3: Confidence levels for various exposure rates

Acceptable Exceedance Fraction	Confidence Level	Number of Samples Required to Reach Confidence Level
1%	90%	Not possible
	75%	Not possible
	50%	30
5%	90%	Not possible
	75%	25
	50%	6
10%	90%	20
	75%	14
	50%	6

Given these results, we proceeded to analyze four sampling strategies at the 90th percentile. Note, that the 90th percentile is the 10% exceedance fraction. The exceedance fraction must be a corporate decision. However, we recommend the use of the 10% exceedance fraction based on the high number of samples required to obtain any level of confidence with the 1% or 5% exceedance fractions, and made this decision for the purposes of this paper in order to develop performance curves for various sampling strategies.

The four sampling protocols were analyzed using performance curves for the group 90th percentile. Step one was to take three or six DRI TWA samples. If all of the DRI TWAs were below the designated percent of the OEL, then the exposure was acceptable, if any one TWA sample was above the OEL, the exposure was unacceptable. If step one did not clearly define

the exposure as either acceptable or unacceptable, then step two was to collect an additional three or four integrated samples. When integrated samples were collected, the 90th percentile of all the samples was compared to the OEL. If the 90th percentile was less than the action limit (50% of the OEL) then the exposure was acceptable. Figure 6 shows the results when 10% of the OEL as measured with the DRI was used as the cut-off for additional sampling. The sample size was either n=3 or n=6 for the DRIs with an additional n=3 or n=4 integrated samples for A and B, respectively. The β error for these sampling protocols is 15% and 5% and the α error is 40% and 50%.

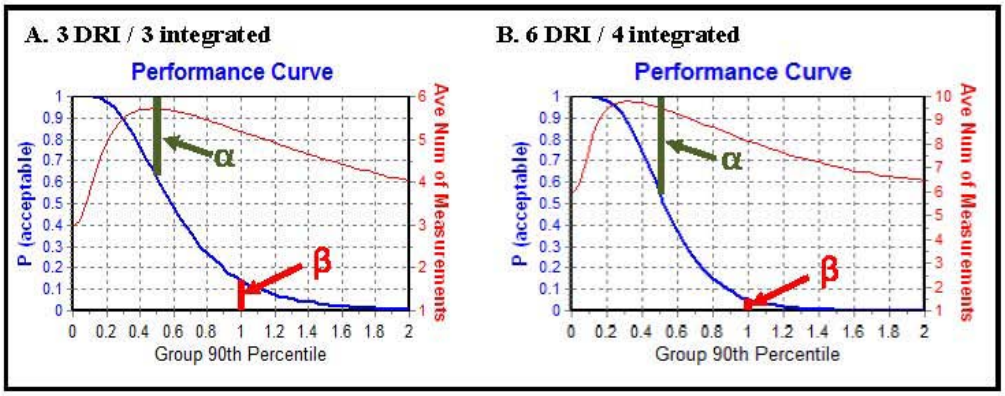

Figure 6: Performance curves with 10% cut-off for DRIs

Figure 7 shows the results for 50% of the OEL break point for DRIs, with n=3 or n=6 for the DRIs with an additional n=3 or n=4 integrated samples for A and B, respectively. The β error for these sampling protocols is 35% and 10% and the α error is 25% and 35%.

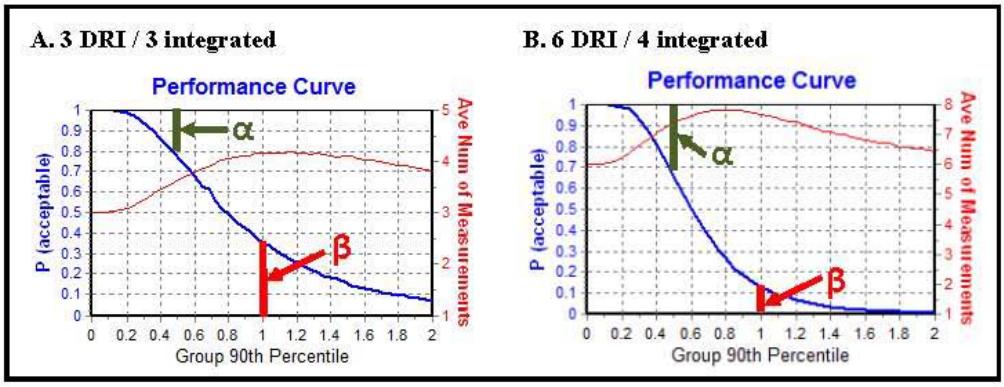

Figure 7: Performance curves with 50% cut-off for DRIs

Table 4 summarizes the four strategies investigated and ranks the order we feel is most to least appropriate for Air Force-wide implementation.

Table 4: Four Exposure Strategies

Rank	DRI Samples	Integrated Samples	When integrated is taken	Rationale
1	3	3	If all DRIs < 50% of the OEL, then the exposure is acceptable or if any one DRI is above OEL, then exposure is unacceptable, else take 3 integrated samples. If the 90% percentile of the combined 6 samples is below the OEL, then the exposure is acceptable	Minimizes the sample number while maintaining adequate confidence in exposure profile
2	3	3	If all DRIs < 10% of the OEL, then the exposure is acceptable or if any one DRI is above OEL, then exposure is unacceptable, else take 3 integrated samples. If the 90% percentile of the combined 6 samples is below the OEL, then the exposure is acceptable	Minimizes the sample number but increases α error
3	6	4	If all DRIs < 50% of the OEL, then the exposure is acceptable or if any one DRI is above OEL, then exposure is unacceptable, else take 4 integrated samples. If the 90% percentile of the combined 10 samples is below the OEL, then the exposure is acceptable	Higher sample number but increases confidence in exposure profile
4	6	4	If all DRIs < 10% of the OEL, then the exposure is acceptable or if any one DRI is above OEL, then exposure is unacceptable, else take 4 integrated samples. If the 90% percentile of the combined 10 samples is below the OEL, then the exposure is acceptable	Higher sample number and α error still high

.

Table 5 outlines the error associated with the four proposed sampling strategies as well as the OSHA compliance method and the AIHA strategy. Of the four methods, we feel the most practical strategy is the 50% cut off with 3 plus 3 samples. This gives reasonable confidence, 65% confident that no more than 10% of the workers are overexposed and 75% confident that unnecessary controls are not put in place. However, the sampling strategy was based on a 10% exceedance fraction.

Table 5: Error associated with sampling strategies with a 10% exceedance fraction

Cut off for additional sampling	DRI samples	Integrated Samples	α error (%) (commander's risk)	β error (%) (employee's risk)
10%	3	3	40	15
	6	4	50	5
50%	3	3	25	35
	6	4	35	10
OSHA		1	1	90
AIHA		6	5	55

Conclusions

Traditional methods including inspector type sampling and the AIHA model do not provide the base level BEE with adequate confidence in the EA to make the appropriate health risk decision. In a typical process with a GSD of 2.5, having n=1 samples and comparing to the OEL, the BEE would only be 10% confident no more than 10% of the employees are overexposed. The AIHA method, with taking 6 samples increases the confidence to 55%. The proposed methods will increase confidence in overall exposure without significantly increasing the BEE's workload. Further work needs to be completed to verify the modeled results.

The EA proposed has many advantages over traditional methods used by base level BEEs. First, the BEE will have a significant improvement in overall exposure assessments

within the industrial setting without significantly increasing the workload. Second, modeling can be used to reduce the amount of air sampling required. Third, using DRIs can improve confidence in characterization without the need for complicated integrated sampling techniques and secondary laboratory analysis. Finally, by using the proposed EA, the BEE will gain confidence in modeling and DRIs, which may be the primary tools available in deployed settings or contingency operations.

Prior to implementation of this plan, a corporate decision needs to be made on what is a clearly acceptable and clearly unacceptable exposure as well as how much confidence the BEE should have to make an informed risk decision.

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NIOSH. (1977). *Occupatiponal Exposure Sampling Strategy Manual, Technical Report 77-13.* Cincinnati: U.S. Department of Health, Education, and Welfare.

Appendix B: Sample Results

The following are copies of the sample results from Bureau Veritas, reprinted in their entirety.

February 03, 2009

TSgt Batten, 4B071
U.S. AIR FORCE
74 AMDS/SGPB
Wright- Patterson AFB, OH

Bureau Veritas Work Order No.:09010407

Reference: FA8900-07-A-9002/WPAT AFB/09N040

Dear TSgt Batten:

Bureau Veritas North America, Inc. received 36 samples on 1/20/2009 for the analyses presented in the following report.

Enclosed is a copy of the Chain-of-Custody record, acknowledging receipt of these samples. Please note that any unused portion of the samples will be discarded 30 days after the date of this report, unless you have requested otherwise.

This material is confidential and is intended solely for the person to whom it is addressed. If this is received in error, please contact the number provided below.

We appreciate the opportunity to assist you. If you have any questions concerning this report, please contact a Client Services Representative at (800) 806-5887.

Sincerely,

Allen Schinsky, CIH
Client Services Representative
cc:

Bureau Veritas North America, Inc.
22345 Roethel Drive
Novi, MI 48375

Main: (248) 344.1770
Fax: (248) 344.2655
www.us.bureauveritas.com

CASE NARRATIVE

Date: *03-Feb-09*

Client: U.S. AIR FORCE

Project: FA8900-07-A-9002/WPAT AFB/09N040

Work Order No 09010407

The results of this report relate only to the samples listed in the body of this report.

Unless otherwise noted below, the following statements apply: 1) all samples were received in acceptable condition, 2) all quality control results associated with this sample set were within acceptable limits and/or do not adversely affect the reported results, and 3) the industrial hygiene results have not been blank corrected.

Analytical Comments for Method N0600PVCXR, sample -001A: Actual value of particulate client blank was -40ug; results have been blank corrected with the average of the client blanks.

Analytical Comments for Method N0600PVCXR, sample -002A: Actual value of particulate client blank was -80ug; results have been blank corrected with the average of the client blanks.

ANALYTICAL RESULTS

Date: *03-Feb-09*

Client: U.S. AIR FORCE **Work Order No:** 09010407

Project: FA8900-07-A-9002/WPAT AFB/09N040

Analyte	Concentration (µg)	Concentration (mg/m³)	Concentration %	Reporting Limit (µg)	Test Method	Date Analyzed /Analyst	
Client ID: S0901083-01A/BK089001 BLANK	**Lab ID:** 001A	**Date Sampled:** 12/17/2008			**Matrix:** PVC 5 Filter, Tared	**Air Vol.(L)** NA	
Particulate, Respirable	<50	--	--	50	NIOSH 0600	01/21/2009	MEN
Cristobalite	<20	--	--	20	NIOSH 7500	01/23/2009	MEN
Quartz	<10	--	--	10	NIOSH 7500	01/23/2009	MEN
Tridymite	<10	--	--	10	NIOSH 7500	01/23/2009	MEN
Client ID: S0901083-02A/BK089002 BLANK	**Lab ID:** 002A	**Date Sampled:** 12/17/2008			**Matrix:** PVC 5 Filter, Tared	**Air Vol.(L)** NA	
Particulate, Respirable	<50	--	--	50	NIOSH 0600	01/21/2009	MEN
Cristobalite	<20	--	--	20	NIOSH 7500	01/23/2009	MEN
Quartz	<10	--	--	10	NIOSH 7500	01/23/2009	MEN
Tridymite	<10	--	--	10	NIOSH 7500	01/23/2009	MEN
Client ID: S0901083-03A/SZ089003	**Lab ID:** 003A	**Date Sampled:** 12/17/2008			**Matrix:** PVC 5 Filter, Tared	**Air Vol.(L)** 424.575	
Particulate, Respirable	250	0.59	--	50	NIOSH 0600	01/21/2009	MEN
Cristobalite	<20	<0.047	<8.0	20	NIOSH 7500	01/23/2009	MEN
Quartz	<10	<0.024	<4.0	10	NIOSH 7500	01/23/2009	MEN
Tridymite	<10	<0.024	<4.0	10	NIOSH 7500	01/23/2009	MEN
Client ID: S0901083-04A/SZ089004	**Lab ID:** 004A	**Date Sampled:** 12/19/2008			**Matrix:** PVC 5 Filter, Tared	**Air Vol.(L)** 352.259	
Particulate, Respirable	150	0.43	--	50	NIOSH 0600	01/21/2009	MEN
Cristobalite	<20	<0.057	<13	20	NIOSH 7500	01/23/2009	MEN
Quartz	<10	<0.028	<6.7	10	NIOSH 7500	01/23/2009	MEN
Tridymite	<10	<0.028	<6.7	10	NIOSH 7500	01/23/2009	MEN
Client ID: S0901083-05A/SZ089005	**Lab ID:** 005A	**Date Sampled:** 12/19/2008			**Matrix:** PVC 5 Filter, Tared	**Air Vol.(L)** 142.517	
Particulate, Respirable	<50	<0.35	--	50	NIOSH 0600	01/21/2009	MEN
Cristobalite	<20	<0.14	--	20	NIOSH 7500	01/23/2009	MEN
Quartz	<10	<0.070	--	10	NIOSH 7500	01/23/2009	MEN
Tridymite	<10	<0.070	--	10	NIOSH 7500	01/23/2009	MEN

ANALYTICAL RESULTS

Date: *03-Feb-09*

Client: U.S. AIR FORCE **Work Order No:** 09010407

Project: FA8900-07-A-9002/WPAT AFB/09N040

Analyte	Concentration (µg)	Concentration (mg/m³)	Concentration %	Reporting Limit (µg)	Test Method	Date Analyzed /Analyst	
Client ID: S0901083-06A/SZ089006 **Lab ID:** 006A **Date Sampled:** 12/22/2008 **Matrix:** PVC 5 Filter, Tared **Air Vol.(L)** 553.4							
Particulate, Respirable	2800	5.1	--	50	NIOSH 0600	01/21/2009	MEN
Cristobalite	<20	<0.036	<0.71	20	NIOSH 7500	01/23/2009	MEN
Quartz	50	0.090	1.8	10	NIOSH 7500	01/23/2009	MEN
Tridymite	<10	<0.018	<0.36	10	NIOSH 7500	01/23/2009	MEN
Client ID: S0901083-07A/SZ089007 **Lab ID:** 007A **Date Sampled:** 12/23/2008 **Matrix:** PVC 5 Filter, Tared **Air Vol.(L)** 405.876							
Particulate, Respirable	130	0.32	--	50	NIOSH 0600	01/21/2009	MEN
Cristobalite	<20	<0.049	<15	20	NIOSH 7500	01/23/2009	MEN
Quartz	<10	<0.025	<7.7	10	NIOSH 7500	01/23/2009	MEN
Tridymite	<10	<0.025	<7.7	10	NIOSH 7500	01/23/2009	MEN
Client ID: S0901083-08A/SZ089008 **Lab ID:** 008A **Date Sampled:** 12/23/2008 **Matrix:** PVC 5 Filter, Tared **Air Vol.(L)** 215.196							
Particulate, Respirable	<50	<0.23	--	50	NIOSH 0600	01/21/2009	MEN
Cristobalite	<20	<0.093	--	20	NIOSH 7500	01/23/2009	MEN
Quartz	<10	<0.046	--	10	NIOSH 7500	01/23/2009	MEN
Tridymite	<10	<0.046	--	10	NIOSH 7500	01/23/2009	MEN
Client ID: S0901083-09A/SZ089009 **Lab ID:** 009A **Date Sampled:** 12/24/2008 **Matrix:** PVC 5 Filter, Tared **Air Vol.(L)** 104.832							
Particulate, Respirable	<50	<0.48	--	50	NIOSH 0600	01/21/2009	MEN
Cristobalite	<20	<0.19	--	20	NIOSH 7500	01/23/2009	MEN
Quartz	<10	<0.095	--	10	NIOSH 7500	01/23/2009	MEN
Tridymite	<10	<0.095	--	10	NIOSH 7500	01/23/2009	MEN
Client ID: S0901083-10A/SZ089010 **Lab ID:** 010A **Date Sampled:** 12/25/2008 **Matrix:** PVC 5 Filter, Tared **Air Vol.(L)** 264.81							
Particulate, Respirable	240	0.91	--	50	NIOSH 0600	01/21/2009	MEN
Cristobalite	<20	<0.076	<8.3	20	NIOSH 7500	01/23/2009	MEN
Quartz	<10	<0.038	<4.2	10	NIOSH 7500	01/23/2009	MEN
Tridymite	<10	<0.038	<4.2	10	NIOSH 7500	01/23/2009	MEN

ANALYTICAL RESULTS

Date: *03-Feb-09*

Client: U.S. AIR FORCE **Work Order No:** 09010407

Project: FA8900-07-A-9002/WPAT AFB/09N040

Analyte	Concentration (µg)	Concentration (mg/m³)	Concentration %	Reporting Limit (µg)	Test Method	Date Analyzed /Analyst	
Client ID: S0901083-11A/SZ089011 **Lab ID:** 011A **Date Sampled:** 12/25/2008 **Matrix:** PVC 5 Filter, Tared **Air Vol.(L)** 131.04							
Particulate, Respirable	<50	<0.38	--	50	NIOSH 0600	01/21/2009	MEN
Cristobalite	<20	<0.15	--	20	NIOSH 7500	01/23/2009	MEN
Quartz	<10	<0.076	--	10	NIOSH 7500	01/23/2009	MEN
Tridymite	<10	<0.076	--	10	NIOSH 7500	01/23/2009	MEN
Client ID: S0901083-12A/SZ089012 **Lab ID:** 012A **Date Sampled:** 12/26/2008 **Matrix:** PVC 5 Filter, Tared **Air Vol.(L)** 481.68							
Particulate, Respirable	1400	2.9	--	50	NIOSH 0600	01/21/2009	MEN
Cristobalite	<20	<0.042	<1.4	20	NIOSH 7500	01/23/2009	MEN
Quartz	31	0.064	2.2	10	NIOSH 7500	01/23/2009	MEN
Tridymite	<10	<0.021	<0.71	10	NIOSH 7500	01/23/2009	MEN
Client ID: S0901083-13A/SZ089013 **Lab ID:** 013A **Date Sampled:** 12/26/2008 **Matrix:** PVC 5 Filter, Tared **Air Vol.(L)** 157.884							
Particulate, Respirable	100	0.63	--	50	NIOSH 0600	01/21/2009	MEN
Cristobalite	<20	<0.13	<20	20	NIOSH 7500	01/23/2009	MEN
Quartz	<10	<0.063	<10	10	NIOSH 7500	01/23/2009	MEN
Tridymite	<10	<0.063	<10	10	NIOSH 7500	01/23/2009	MEN
Client ID: S0901083-14A/SZ089014 **Lab ID:** 014A **Date Sampled:** 12/27/2008 **Matrix:** PVC 5 Filter, Tared **Air Vol.(L)** 138.006							
Particulate, Respirable	130	0.94	--	50	NIOSH 0600	01/21/2009	MEN
Cristobalite	<20	<0.14	<15	20	NIOSH 7500	01/23/2009	MEN
Quartz	<10	<0.072	<7.7	10	NIOSH 7500	01/23/2009	MEN
Tridymite	<10	<0.072	<7.7	10	NIOSH 7500	01/23/2009	MEN
Client ID: S0901083-15A/SZ089015 **Lab ID:** 015A **Date Sampled:** 12/27/2008 **Matrix:** PVC 5 Filter, Tared **Air Vol.(L)** 154.242							
Particulate, Respirable	<50	<0.32	--	50	NIOSH 0600	01/21/2009	MEN
Cristobalite	<20	<0.13	--	20	NIOSH 7500	01/23/2009	MEN
Quartz	<10	<0.065	--	10	NIOSH 7500	01/23/2009	MEN
Tridymite	<10	<0.065	--	10	NIOSH 7500	01/23/2009	MEN

ANALYTICAL RESULTS

Date: *03-Feb-09*

Client: U.S. AIR FORCE **Work Order No:** 09010407

Project: FA8900-07-A-9002/WPAT AFB/09N040

Analyte	Concentration (µg)	Concentration (mg/m³)	Concentration %	Reporting Limit (µg)	Test Method	Date Analyzed /Analyst	
Client ID: S0901083-16A/SZ089016 **Lab ID:** 016A **Date Sampled:** 12/28/2008 **Matrix:** PVC 5 Filter, Tared **Air Vol.(L)** 265.5							
Particulate, Respirable	450	1.7	--	50	NIOSH 0600	01/21/2009	MEN
Cristobalite	<20	<0.075	<4.4	20	NIOSH 7500	01/23/2009	MEN
Quartz	<10	<0.038	<2.2	10	NIOSH 7500	01/23/2009	MEN
Tridymite	<10	<0.038	<2.2	10	NIOSH 7500	01/23/2009	MEN
Client ID: S0901083-17A/SZ089017 **Lab ID:** 017A **Date Sampled:** 12/28/2008 **Matrix:** PVC 5 Filter, Tared **Air Vol.(L)** 140.715							
Particulate, Respirable	100	0.71	--	50	NIOSH 0600	01/21/2009	MEN
Cristobalite	<20	<0.14	<20	20	NIOSH 7500	01/23/2009	MEN
Quartz	<10	<0.071	<10	10	NIOSH 7500	01/23/2009	MEN
Tridymite	<10	<0.071	<10	10	NIOSH 7500	01/23/2009	MEN
Client ID: S0901083-18A/SZ089018 **Lab ID:** 018A **Date Sampled:** 12/29/2008 **Matrix:** PVC 5 Filter, Tared **Air Vol.(L)** 534.6							
Particulate, Respirable	220	0.41	--	50	NIOSH 0600	01/21/2009	MEN
Cristobalite	<20	<0.037	<9.1	20	NIOSH 7500	01/23/2009	MEN
Quartz	<10	<0.019	<4.5	10	NIOSH 7500	01/23/2009	MEN
Tridymite	<10	<0.019	<4.5	10	NIOSH 7500	01/23/2009	MEN
Client ID: S0901083-19A/SZ089019 **Lab ID:** 019A **Date Sampled:** 12/29/2008 **Matrix:** PVC 5 Filter, Tared **Air Vol.(L)** 133.65							
Particulate, Respirable	130	0.97	--	50	NIOSH 0600	01/21/2009	MEN
Cristobalite	<20	<0.15	<15	20	NIOSH 7500	01/23/2009	MEN
Quartz	<10	<0.075	<7.7	10	NIOSH 7500	01/23/2009	MEN
Tridymite	<10	<0.075	<7.7	10	NIOSH 7500	01/23/2009	MEN
Client ID: S0901083-20A/SZ089020 **Lab ID:** 020A **Date Sampled:** 12/30/2008 **Matrix:** PVC 5 Filter, Tared **Air Vol.(L)** 247.611							
Particulate, Respirable	170	0.69	--	50	NIOSH 0600	01/21/2009	MEN
Cristobalite	<20	<0.081	<12	20	NIOSH 7500	01/23/2009	MEN
Quartz	<10	<0.040	<5.9	10	NIOSH 7500	01/23/2009	MEN
Tridymite	<10	<0.040	<5.9	10	NIOSH 7500	01/23/2009	MEN

ANALYTICAL RESULTS

Date: *03-Feb-09*

Client: U.S. AIR FORCE **Work Order No:** 09010407

Project: FA8900-07-A-9002/WPAT AFB/09N040

Analyte	Concentration (µg)	Concentration (mg/m³)	Concentration %	Reporting Limit (µg)	Test Method	Date Analyzed /Analyst	
Client ID: S0901083-21A/SZ089021 **Lab ID:** 021A **Date Sampled:** 12/30/2008 **Matrix:** PVC 5 Filter, Tared **Air Vol.(L)** 165.981							
Particulate, Respirable	60	0.36	--	50	NIOSH 0600	01/21/2009	MEN
Cristobalite	<20	<0.12	<33	20	NIOSH 7500	01/23/2009	MEN
Quartz	<10	<0.060	<17	10	NIOSH 7500	01/23/2009	MEN
Tridymite	<10	<0.060	<17	10	NIOSH 7500	01/23/2009	MEN
Client ID: S0901083-22A/SZ089022 **Lab ID:** 022A **Date Sampled:** 12/31/2008 **Matrix:** PVC 5 Filter, Tared **Air Vol.(L)** NA							
Particulate, Respirable	120	--	--	50	NIOSH 0600	01/21/2009	MEN
Cristobalite	<20	--	<17	20	NIOSH 7500	01/23/2009	MEN
Quartz	<10	--	<8.3	10	NIOSH 7500	01/23/2009	MEN
Tridymite	<10	--	<8.3	10	NIOSH 7500	01/23/2009	MEN
Client ID: S0901083-23A/SZ089023 **Lab ID:** 023A **Date Sampled:** 12/31/2008 **Matrix:** PVC 5 Filter, Tared **Air Vol.(L)** 141.076							
Particulate, Respirable	<50	<0.35	--	50	NIOSH 0600	01/21/2009	MEN
Cristobalite	<20	<0.14	--	20	NIOSH 7500	01/23/2009	MEN
Quartz	<10	<0.071	--	10	NIOSH 7500	01/23/2009	MEN
Tridymite	<10	<0.071	--	10	NIOSH 7500	01/23/2009	MEN
Client ID: S0901083-24A/SZ099024 **Lab ID:** 024A **Date Sampled:** 1/2/2009 **Matrix:** PVC 5 Filter, Tared **Air Vol.(L)** NA							
Particulate, Respirable	230	--	--	50	NIOSH 0600	01/21/2009	MEN
Cristobalite	<20	--	<8.7	20	NIOSH 7500	01/23/2009	MEN
Quartz	<10	--	<4.3	10	NIOSH 7500	01/23/2009	MEN
Tridymite	<10	--	<4.3	10	NIOSH 7500	01/23/2009	MEN
Client ID: S0901083-25A/SZ099025 **Lab ID:** 025A **Date Sampled:** 1/3/2009 **Matrix:** PVC 5 Filter, Tared **Air Vol.(L)** 207.592							
Particulate, Respirable	60	0.29	--	50	NIOSH 0600	01/21/2009	MEN
Cristobalite	<20	<0.096	<33	20	NIOSH 7500	01/23/2009	MEN
Quartz	<10	<0.048	<17	10	NIOSH 7500	01/23/2009	MEN
Tridymite	<10	<0.048	<17	10	NIOSH 7500	01/23/2009	MEN

ANALYTICAL RESULTS

Date: *03-Feb-09*

Client: U.S. AIR FORCE

Work Order No: 09010407

Project: FA8900-07-A-9002/WPAT AFB/09N040

Analyte	Concentration (µg)	Concentration (mg/m³)	Concentration %	Reporting Limit (µg)	Test Method	Date Analyzed /Analyst	
Client ID: S0901083-26A/SZ099026 **Lab ID:** 026A **Date Sampled:** 1/3/2009					**Matrix:** PVC 5 Filter, Tared	**Air Vol.(L)** 148.28	
Particulate, Respirable	<50	<0.34	--	50	NIOSH 0600	01/21/2009	MEN
Cristobalite	<20	<0.13	--	20	NIOSH 7500	01/23/2009	MEN
Quartz	<10	<0.067	--	10	NIOSH 7500	01/23/2009	MEN
Tridymite	<10	<0.067	--	10	NIOSH 7500	01/23/2009	MEN
Client ID: S0901083-27A/SZ099027 **Lab ID:** 027A **Date Sampled:** 1/4/2009					**Matrix:** PVC 5 Filter, Tared	**Air Vol.(L)** 293.22	
Particulate, Respirable	150	0.51	--	50	NIOSH 0600	01/21/2009	MEN
Cristobalite	<20	<0.068	<13	20	NIOSH 7500	01/23/2009	MEN
Quartz	<10	<0.034	<6.7	10	NIOSH 7500	01/23/2009	MEN
Tridymite	<10	<0.034	<6.7	10	NIOSH 7500	01/23/2009	MEN
Client ID: S0901083-28A/SZ099028 **Lab ID:** 028A **Date Sampled:** 1/4/2009					**Matrix:** PVC 5 Filter, Tared	**Air Vol.(L)** 157.47	
Particulate, Respirable	<50	<0.32	--	50	NIOSH 0600	01/21/2009	MEN
Cristobalite	<20	<0.13	--	20	NIOSH 7500	01/23/2009	MEN
Quartz	<10	<0.064	--	10	NIOSH 7500	01/23/2009	MEN
Tridymite	<10	<0.064	--	10	NIOSH 7500	01/23/2009	MEN
Client ID: S0901083-29A/SZ099031 **Lab ID:** 029A **Date Sampled:** 12/18/2008					**Matrix:** PVC 5 Filter, Tared	**Air Vol.(L)** 1070.5	
Particulate, Respirable	190	0.18	--	50	NIOSH 0600	01/21/2009	MEN
Cristobalite	<20	<0.019	<11	20	NIOSH 7500	01/23/2009	MEN
Quartz	<10	<0.0093	<5.3	10	NIOSH 7500	01/23/2009	MEN
Tridymite	<10	<0.0093	<5.3	10	NIOSH 7500	01/23/2009	MEN

ANALYTICAL RESULTS

Date: *03-Feb-09*

Client: U.S. AIR FORCE
Work Order No: 09010407

Project: FA8900-07-A-9002/WPAT AFB/09N040

Lab ID: 09010407-030A
Client Sample ID: S0901083-30A/GM099029

Matrix: BULK
Tag Number:

Collection Date: 12/14/2008

Analyses	Result	Reporting Limit	Qual	Units	DF	Date Analyzed	Analyst
NIOSH 7500							
Cristobalite	ND	2.0		wt%	1	1/29/2009	MEN
Quartz	ND	1.0		wt%	1	1/29/2009	MEN
Tridymite	ND	1.0		wt%	1	1/29/2009	MEN

Qualifiers:

ND - Not Detected at the Reporting Limit (RL).
J - Analyte detected below the Reporting Limit
B - Analyte detected in the associated Method Blank
* - Value exceeds Maximum Contaminant Level
S - Spike Recovery outside accepted recovery limits
R - RPD outside accepted recovery limits
E - Value above quantitation range
T - Tentatively Identified Compound (TIC)

ANALYTICAL RESULTS

Date: *03-Feb-09*

Client: U.S. AIR FORCE **Work Order No:** 09010407

Project: FA8900-07-A-9002/WPAT AFB/09N040

Lab ID: 09010407-031A **Client Sample ID:** S0901083-31A/GM099030

Matrix: BULK **Tag Number:**

Collection Date: 12/14/2008

Analyses	Result	Reporting Limit	Qual	Units	DF	Date Analyzed	Analyst
NIOSH 7500							
Cristobalite	ND	2.0		wt%	1	1/29/2009	MEN
Quartz	ND	1.0		wt%	1	1/29/2009	MEN
Tridymite	ND	1.0		wt%	1	1/29/2009	MEN

Qualifiers:

ND - Not Detected at the Reporting Limit (RL).
J - Analyte detected below the Reporting Limit
B - Analyte detected in the associated Method Blank
* - Value exceeds Maximum Contaminant Level
S - Spike Recovery outside accepted recovery limits
R - RPD outside accepted recovery limits
E - Value above quantitation range
T - Tentatively Identified Compound (TIC)

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ANALYTICAL RESULTS

Date: *03-Feb-09*

Client: U.S. AIR FORCE
Work Order No: 09010407

Project: FA8900-07-A-9002/WPAT AFB/09N040

Lab ID: 09010407-032A
Client Sample ID: S0901083-32A/GD099032

Matrix: BULK
Tag Number:

Collection Date: 12/18/2008

Analyses	Result	Reporting Limit	Qual	Units	DF	Date Analyzed	Analyst
NIOSH 7500							
Cristobalite	ND	2.0		wt%	1	1/29/2009	MEN
Quartz	1.1	1.0		wt%	1	1/29/2009	MEN
Tridymite	ND	1.0		wt%	1	1/29/2009	MEN

Qualifiers:

ND - Not Detected at the Reporting Limit (RL).
J - Analyte detected below the Reporting Limit
B - Analyte detected in the associated Method Blank
* - Value exceeds Maximum Contaminant Level
S - Spike Recovery outside accepted recovery limits
R - RPD outside accepted recovery limits
E - Value above quantitation range
T - Tentatively Identified Compound (TIC)

ANALYTICAL RESULTS

Date: *03-Feb-09*

Client: U.S. AIR FORCE
Work Order No: 09010407

Project: FA8900-07-A-9002/WPAT AFB/09N040

Lab ID: 09010407-033A
Client Sample ID: S0901083-33A/GD099033

Matrix: BULK
Tag Number:

Collection Date: 12/18/2008

Analyses	Result	Reporting Limit	Qual	Units	DF	Date Analyzed	Analyst
NIOSH 7500							
Cristobalite	ND	2.0		wt%	1	1/29/2009	MEN
Quartz	1.1	1.0		wt%	1	1/29/2009	MEN
Tridymite	ND	1.0		wt%	1	1/29/2009	MEN

Qualifiers:

ND - Not Detected at the Reporting Limit (RL).
J - Analyte detected below the Reporting Limit
B - Analyte detected in the associated Method Blank
* - Value exceeds Maximum Contaminant Level
S - Spike Recovery outside accepted recovery limits
R - RPD outside accepted recovery limits
E - Value above quantitation range
T - Tentatively Identified Compound (TIC)

ANALYTICAL RESULTS

Date: *03-Feb-09*

Client: U.S. AIR FORCE
Work Order No: 09010407

Project: FA8900-07-A-9002/WPAT AFB/09N040

Lab ID: 09010407-034A
Client Sample ID: S0901083-34A/GD099034

Matrix: BULK
Tag Number:

Collection Date: 12/18/2008

Analyses	Result	Reporting Limit	Qual	Units	DF	Date Analyzed	Analyst
NIOSH 7500							
Cristobalite	ND	2.0		wt%	1	1/29/2009	MEN
Quartz	2.2	1.0		wt%	1	1/29/2009	MEN
Tridymite	ND	1.0		wt%	1	1/29/2009	MEN

Qualifiers:

ND - Not Detected at the Reporting Limit (RL).
J - Analyte detected below the Reporting Limit
B - Analyte detected in the associated Method Blank
* - Value exceeds Maximum Contaminant Level
S - Spike Recovery outside accepted recovery limits
R - RPD outside accepted recovery limits
E - Value above quantitation range
T - Tentatively Identified Compound (TIC)

ANALYTICAL RESULTS

Date: *03-Feb-09*

Client: U.S. AIR FORCE **Work Order No:** 09010407

Project: FA8900-07-A-9002/WPAT AFB/09N040

Lab ID: 09010407-035A **Client Sample ID:** S0901083-35A/GD099035

Matrix: BULK **Tag Number:**

Collection Date: 12/18/2008

Analyses	Result	Reporting Limit	Qual	Units	DF	Date Analyzed	Analyst
NIOSH 7500							
Cristobalite	ND	2.0		wt%	1	1/29/2009	MEN
Quartz	1.7	1.0		wt%	1	1/29/2009	MEN
Tridymite	ND	1.0		wt%	1	1/29/2009	MEN

Qualifiers:

ND - Not Detected at the Reporting Limit (RL).
J - Analyte detected below the Reporting Limit
B - Analyte detected in the associated Method Blank
* - Value exceeds Maximum Contaminant Level
S - Spike Recovery outside accepted recovery limits
R - RPD outside accepted recovery limits
E - Value above quantitation range
T - Tentatively Identified Compound (TIC)

ANALYTICAL RESULTS

Date: *03-Feb-09*

Client: U.S. AIR FORCE **Work Order No:** 09010407

Project: FA8900-07-A-9002/WPAT AFB/09N040

Lab ID: 09010407-036A **Client Sample ID:** S0901083-36A/GD099036

Matrix: BULK **Tag Number:**

Collection Date: 12/18/2008

Analyses	Result	Reporting Limit	Qual	Units	DF	Date Analyzed	Analyst
NIOSH 7500							
Cristobalite	ND	2.0		wt%	1	1/29/2009	MEN
Quartz	1.1	1.0		wt%	1	1/29/2009	MEN
Tridymite	ND	1.0		wt%	1	1/29/2009	MEN

Qualifiers:

ND - Not Detected at the Reporting Limit (RL).
J - Analyte detected below the Reporting Limit
B - Analyte detected in the associated Method Blank
* - Value exceeds Maximum Contaminant Level
S - Spike Recovery outside accepted recovery limits
R - RPD outside accepted recovery limits
E - Value above quantitation range
T - Tentatively Identified Compound (TIC)

ANALYTICAL RESULTS

Date: *18-Feb-09*

CLIENT:	USAF SAM/OETHA	**Sample Type:**	Bulk
Work Order No.:	A0902084	**Date Received:**	2/13/2009
Client Reference:	CONTRACT# FA8900-07-A-9002/WRIGHT-PATTER/0	**Report Date:**	2/18/2009 3:00:4
Method Referenc	Materials Characterization by Light Microscopy		

Lab ID	Client Sample ID	Analyst	Date Sampled	Date Analyzed
001A	***S0902108-01A/GM099029***	JP	12/14/2008	02/18/2009

Layer	POB	Sample Morphology	Asbestos	%	Other Fibers	%	Particulate	%
(1)	100	Non-homogeneous Black Granular Material	None Detected		Non-Detected		Anthracite Coal Bituminous Coal	90% 10%

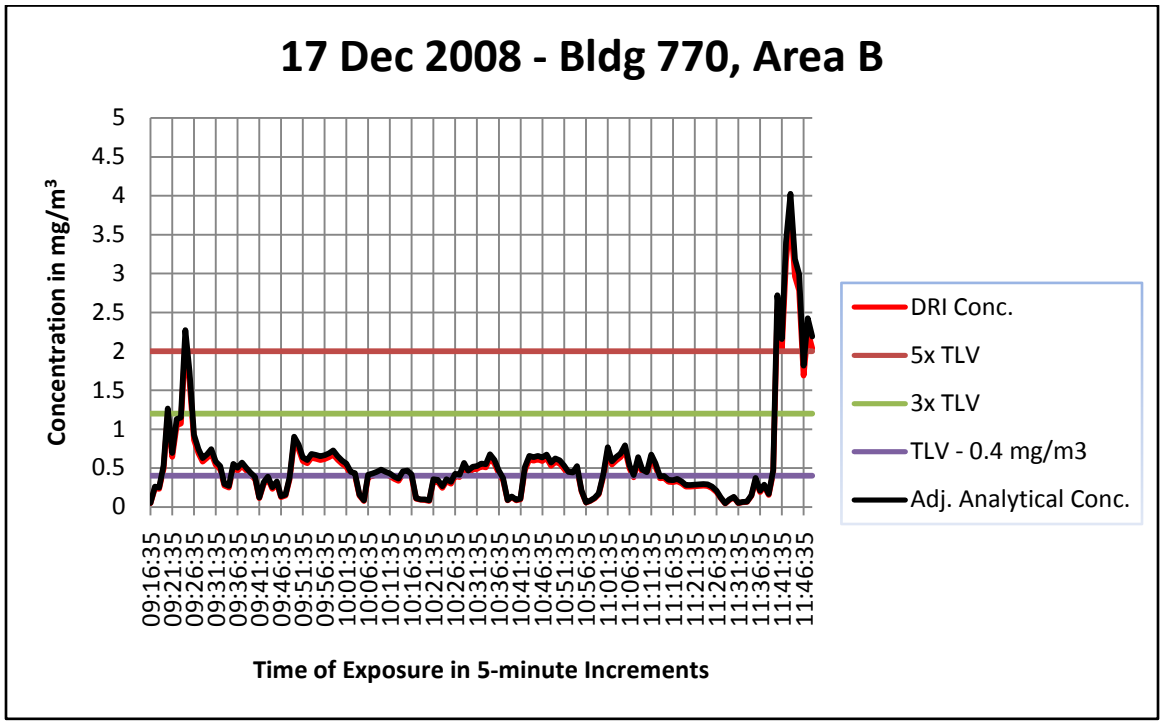
Lab ID	Client Sample ID	Analyst	Date Sampled	Date Analyzed
002A	***S0902108-02A/GM099030***	JP	12/14/2008	02/18/2009

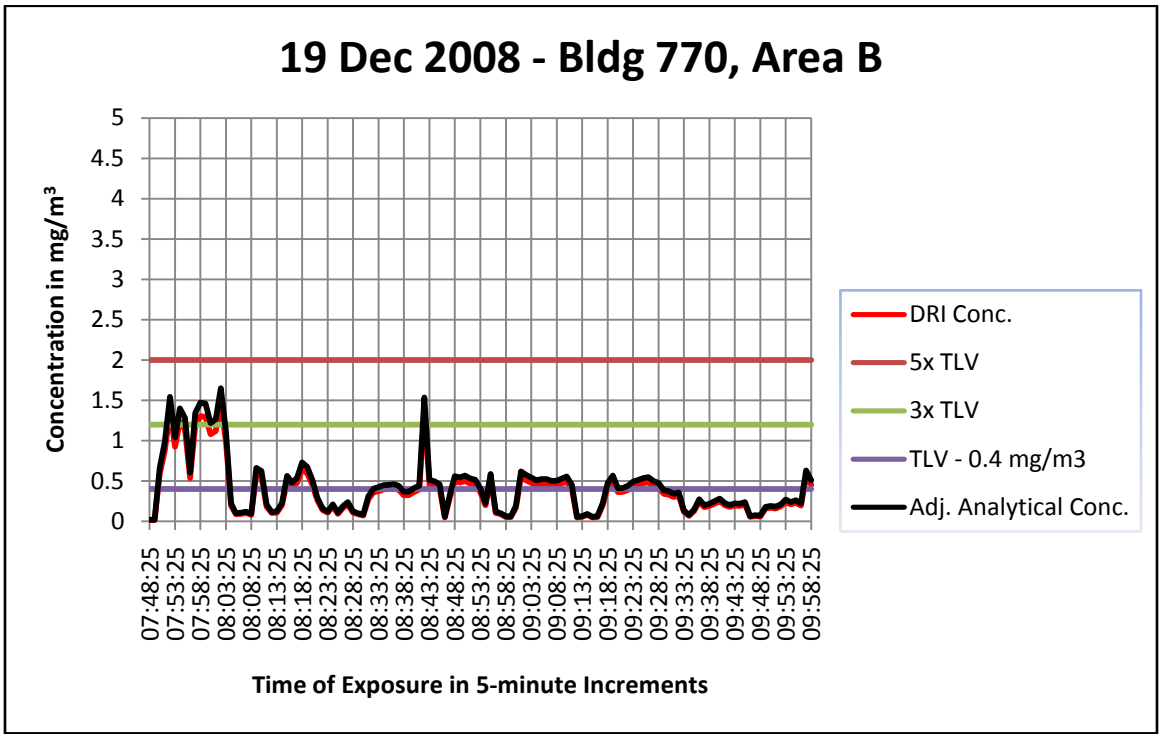
Layer	POB	Sample Morphology	Asbestos	%	Other Fibers	%	Particulate	%
(1)	100	Non-homogeneous Black Granular Material	None Detected		Non-Detected		Anthracite Coal Bituminous Coal	5% 95%

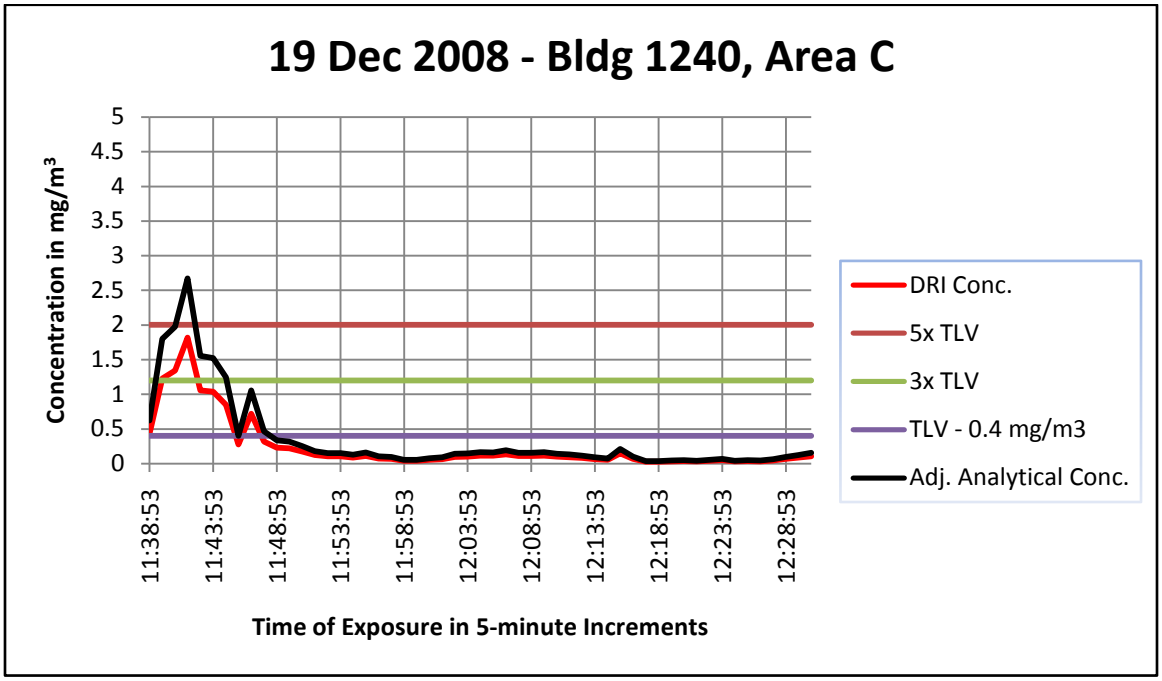
Analyst(s) Name/Date: J Peterson 2/18/2009

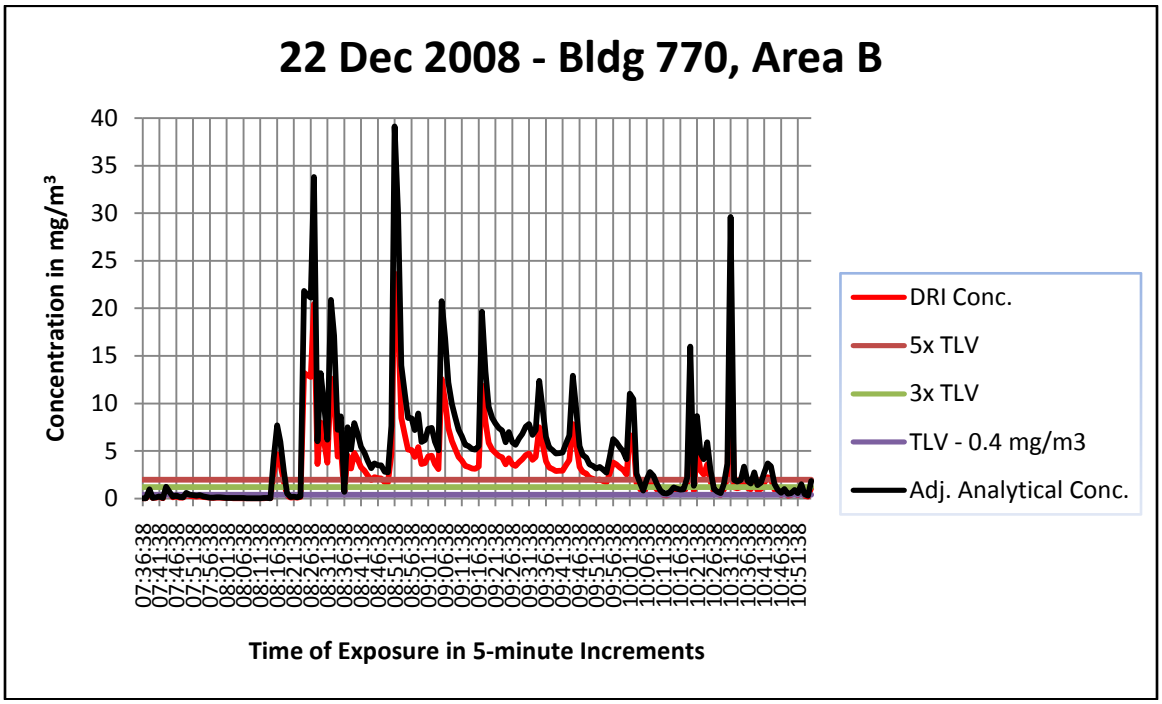
Appendix C: Exposure Assessment Graphs

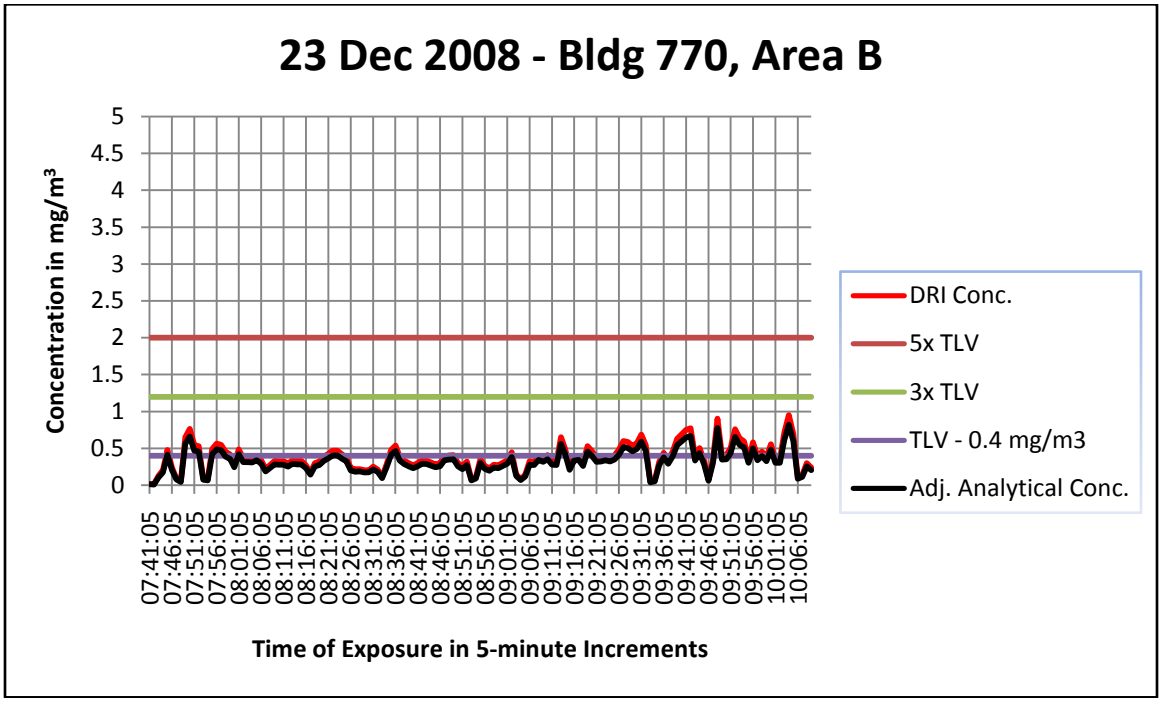
The following figures show the 1-minute average concentrations of particulates during each of the 26 sampling events. Overlaid on the graphs are the ACGIH® TLV® for anthracite coal dust, the 30-minute excursion limit at three times the TLV®, and the upper excursion limit at five times the TLV®. Lastly, the red line shows the concentrations based on the DRI, while the black line is the adjusted concentration equaling the analytical results.

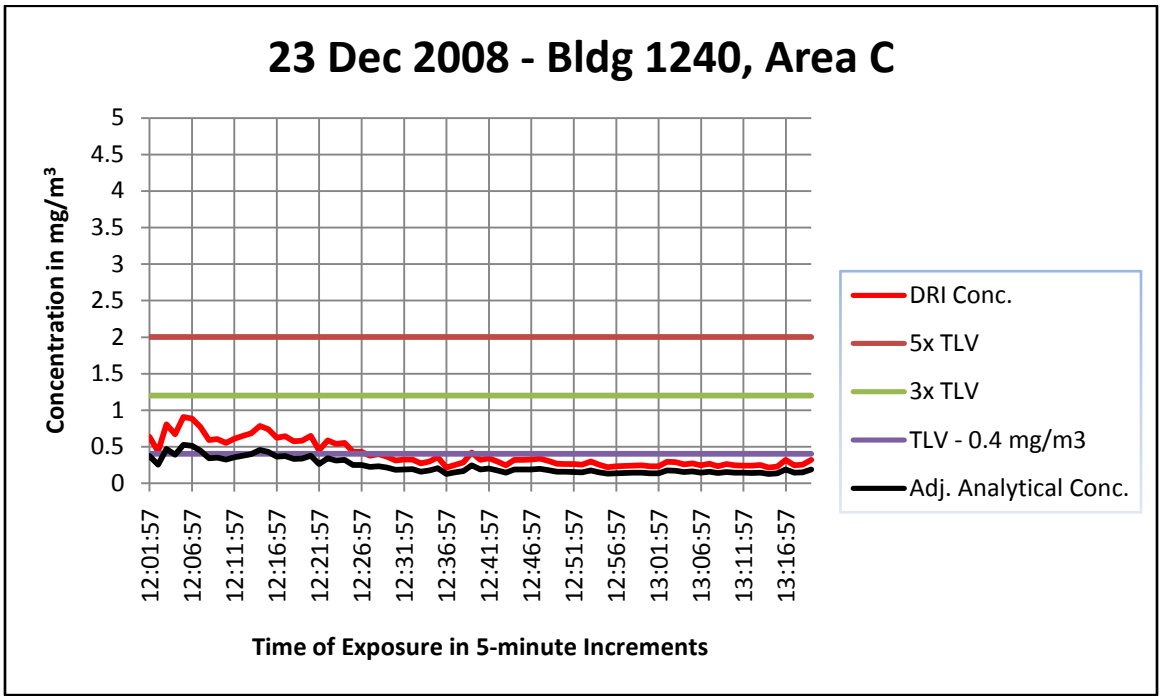


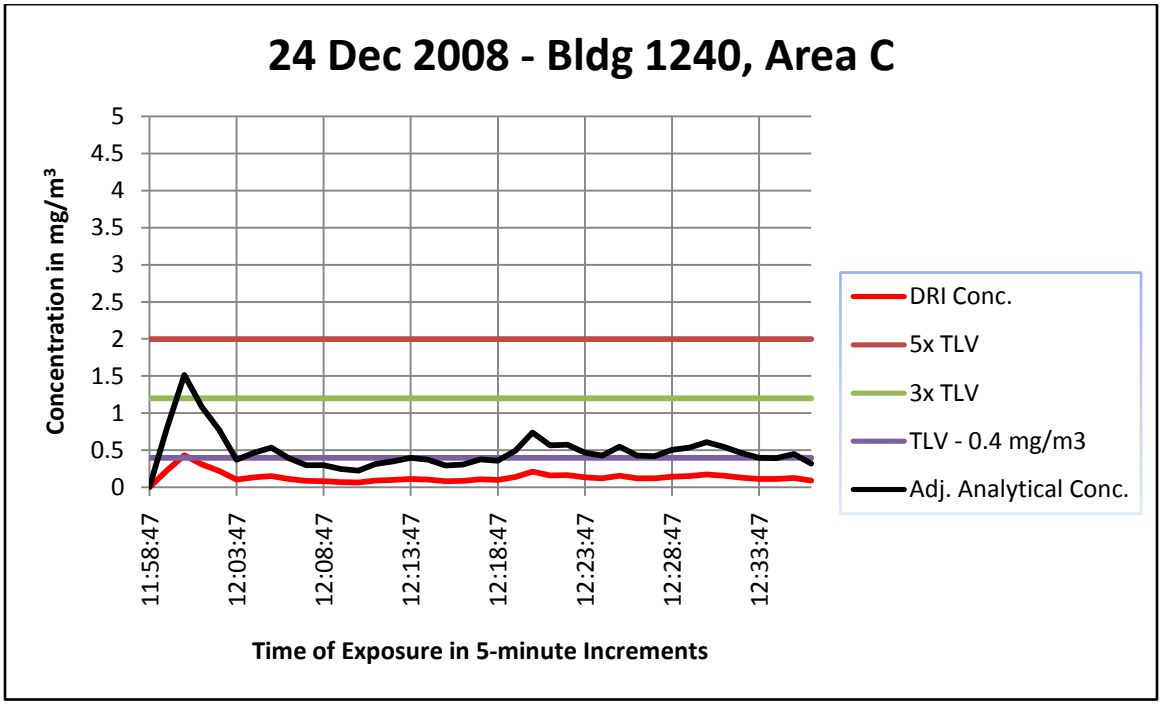

19 Dec 2008 - Bldg 770, Area B
Concentration in mg/m³
5
4.5
4
3.5
3
2.5
2
1.5
1
0.5
0
07:48:25
07:53:25
07:58:25
08:03:25
08:08:25
08:13:25
08:18:25
08:23:25
08:28:25
08:33:25
08:38:25
08:43:25
08:48:25
08:53:25
08:58:25
09:03:25
09:08:25
09:13:25
09:18:25
09:23:25
09:28:25
09:33:25
09:38:25
09:43:25
09:48:25
09:53:25
09:58:25
Time of Exposure in 5-minute Increments
DRI Conc.
5x TLV
3x TLV
TLV - 0.4 mg/m3
Adj. Analytical Conc.

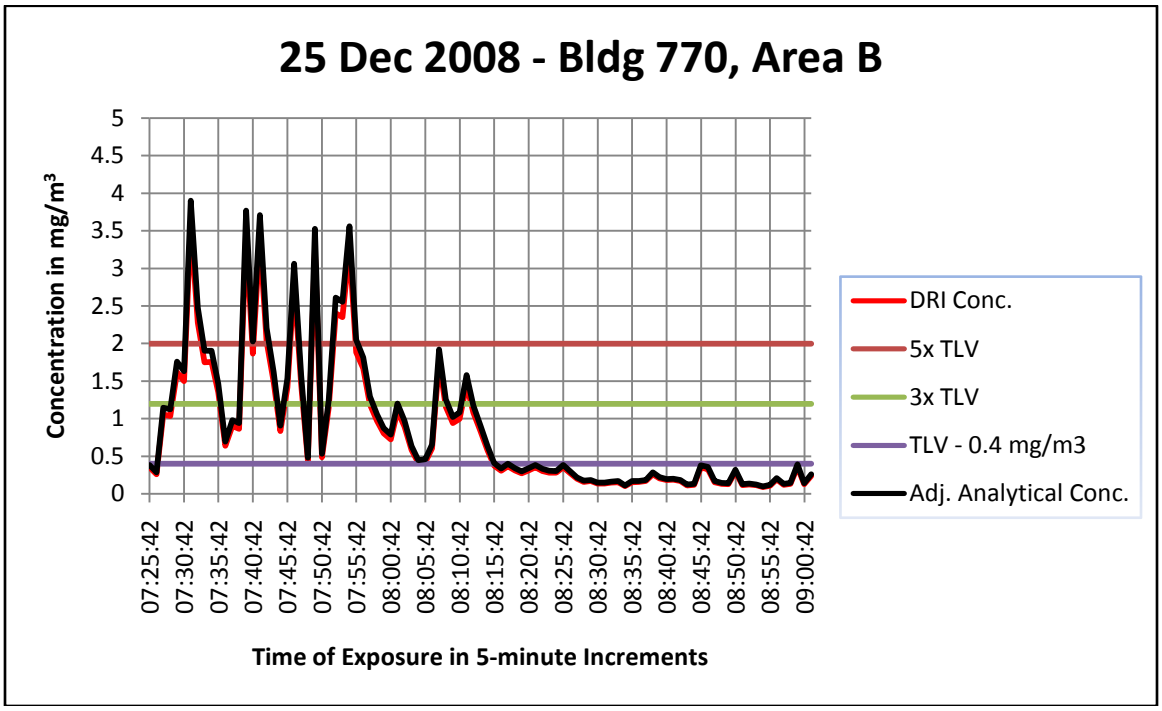

19 Dec 2008 - Bldg 1240, Area C
Concentration in mg/m³
5
4.5
4
3.5
3
2.5
2
1.5
1
0.5
0
11:38:53
11:43:53
11:48:53
11:53:53
11:58:53
12:03:53
12:08:53
12:13:53
12:18:53
12:23:53
12:28:53
Time of Exposure in 5-minute Increments
DRI Conc.
5x TLV
3x TLV
TLV - 0.4 mg/m3
Adj. Analytical Conc.

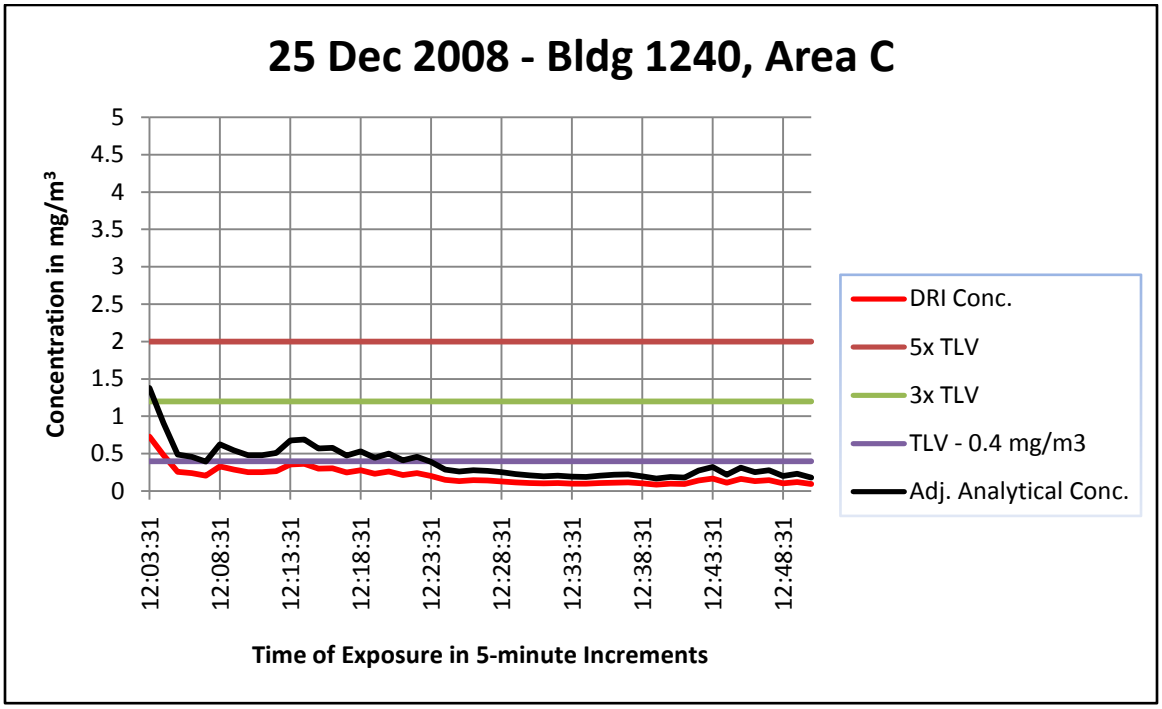

22 Dec 2008 - Bldg 770, Area B
Concentration in mg/m³
40
35
30
25
20
15
10
5
0
07:36:38
07:41:38
07:46:38
07:51:38
07:56:38
08:01:38
08:06:38
08:11:38
08:16:38
08:21:38
08:26:38
08:31:38
08:36:38
08:41:38
08:46:38
08:51:38
08:56:38
09:01:38
09:06:38
09:11:38
09:16:38
09:21:38
09:26:38
09:31:38
09:36:38
09:41:38
09:46:38
09:51:38
09:56:38
10:01:38
10:06:38
10:11:38
10:16:38
10:21:38
10:26:38
10:31:38
10:36:38
10:41:38
10:46:38
10:51:38
Time of Exposure in 5-minute Increments
DRI Conc.
5x TLV
3x TLV
TLV - 0.4 mg/m3
Adj. Analytical Conc.

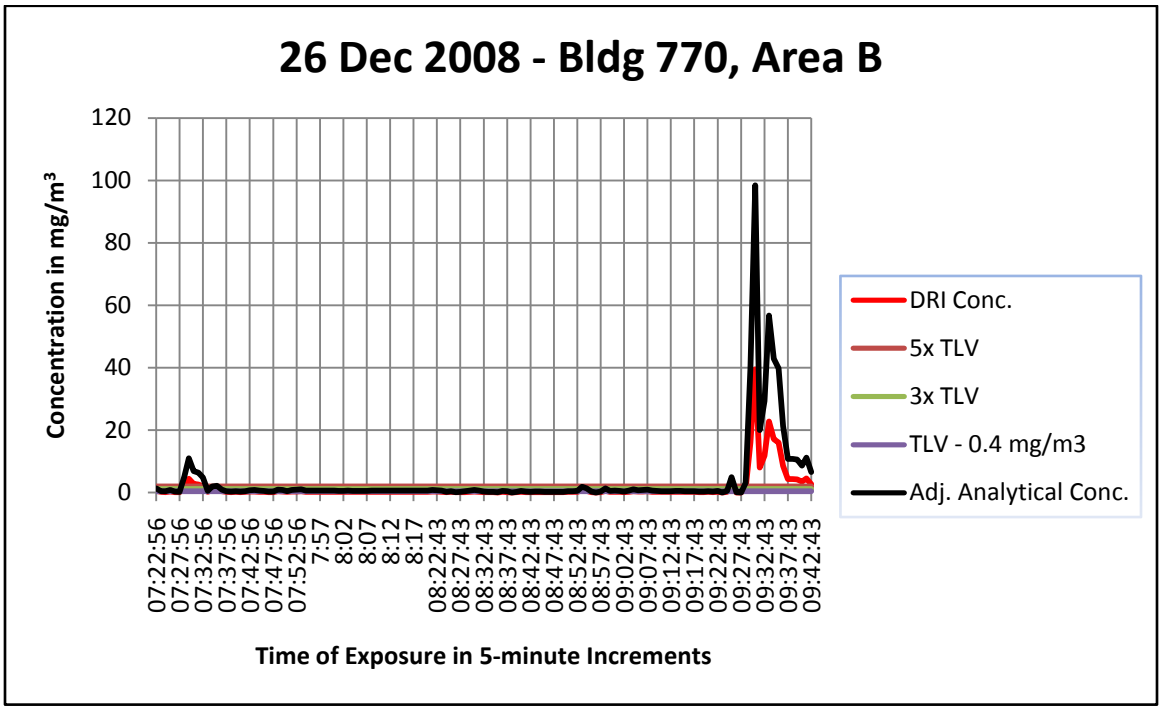

23 Dec 2008 - Bldg 770, Area B
Concentration in mg/m³
5
4.5
4
3.5
3
2.5
2
1.5
1
0.5
0
07:41:05
07:46:05
07:51:05
07:56:05
08:01:05
08:06:05
08:11:05
08:16:05
08:21:05
08:26:05
08:31:05
08:36:05
08:41:05
08:46:05
08:51:05
08:56:05
09:01:05
09:06:05
09:11:05
09:16:05
09:21:05
09:26:05
09:31:05
09:36:05
09:41:05
09:46:05
09:51:05
09:56:05
10:01:05
10:06:05
Time of Exposure in 5-minute Increments
DRI Conc.
5x TLV
3x TLV
TLV - 0.4 mg/m3
Adj. Analytical Conc.

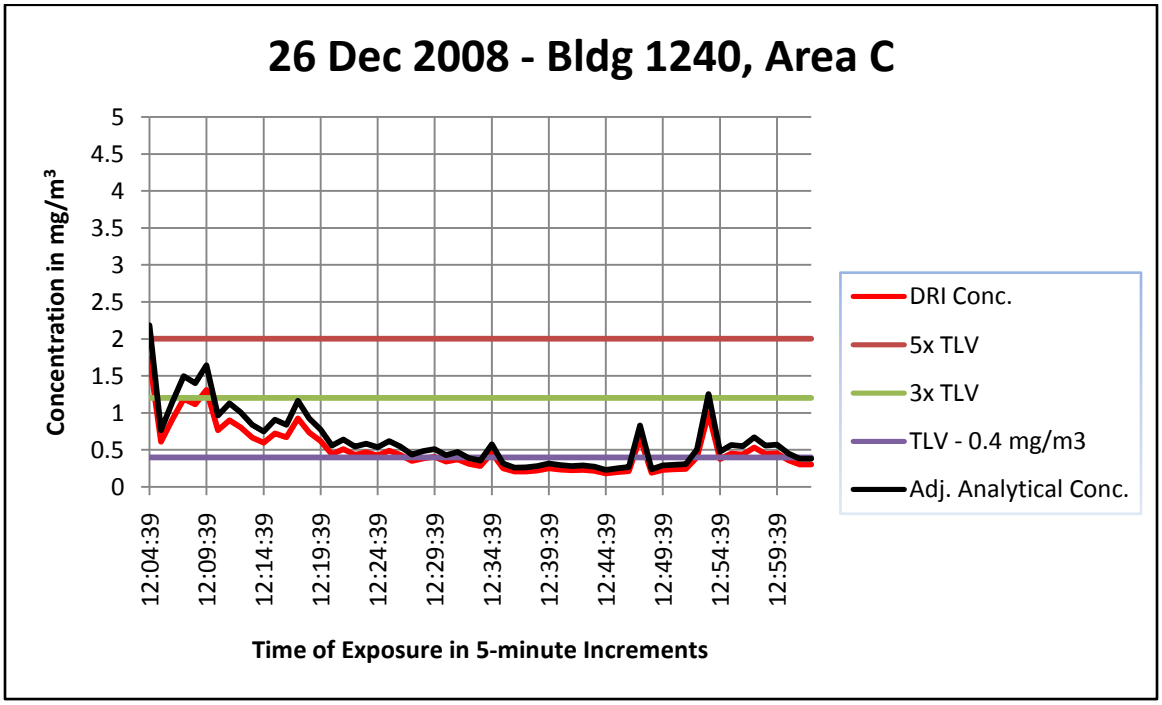

23 Dec 2008 - Bldg 1240, Area C
Concentration in mg/m³
5
4.5
4
3.5
3
2.5
2
1.5
1
0.5
0
12:01:57
12:06:57
12:11:57
12:16:57
12:21:57
12:26:57
12:31:57
12:36:57
12:41:57
12:46:57
12:51:57
12:56:57
13:01:57
13:06:57
13:11:57
13:16:57
Time of Exposure in 5-minute Increments
DRI Conc.
5x TLV
3x TLV
TLV - 0.4 mg/m3
Adj. Analytical Conc.

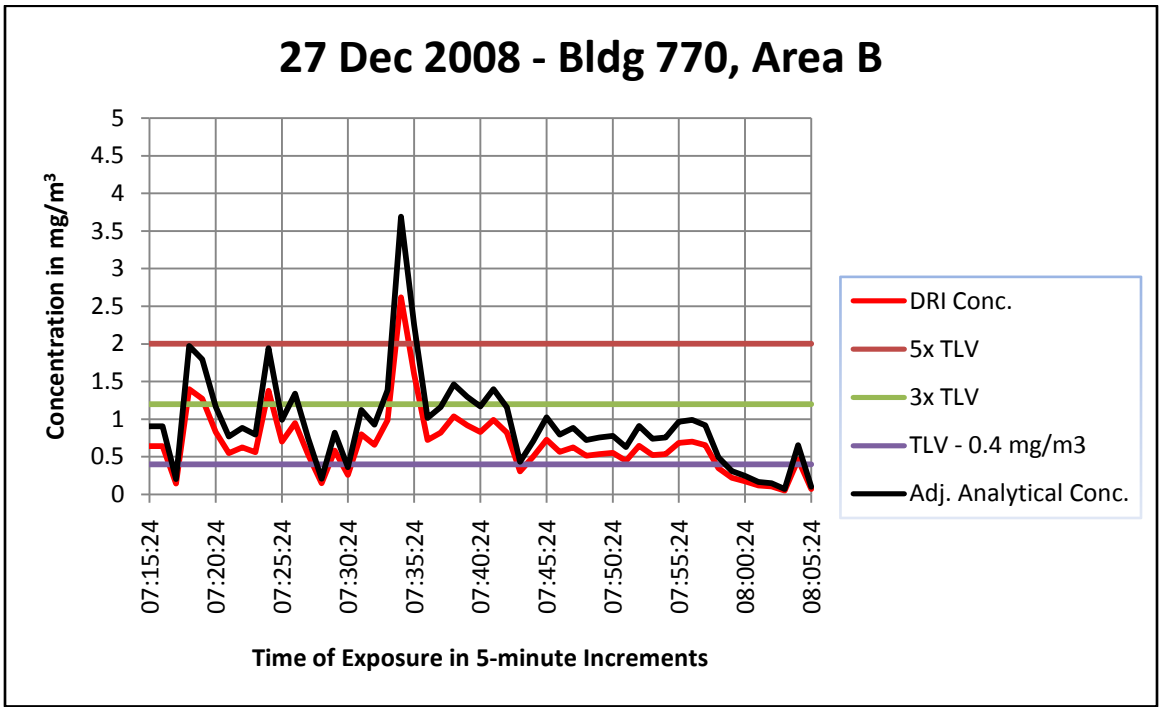

24 Dec 2008 - Bldg 1240, Area C
Concentration in mg/m³
5
4.5
4
3.5
3
2.5
2
1.5
1
0.5
0
11:58:47
12:03:47
12:08:47
12:13:47
12:18:47
12:23:47
12:28:47
12:33:47
Time of Exposure in 5-minute Increments
DRI Conc.
5x TLV
3x TLV
TLV - 0.4 mg/m3
Adj. Analytical Conc.

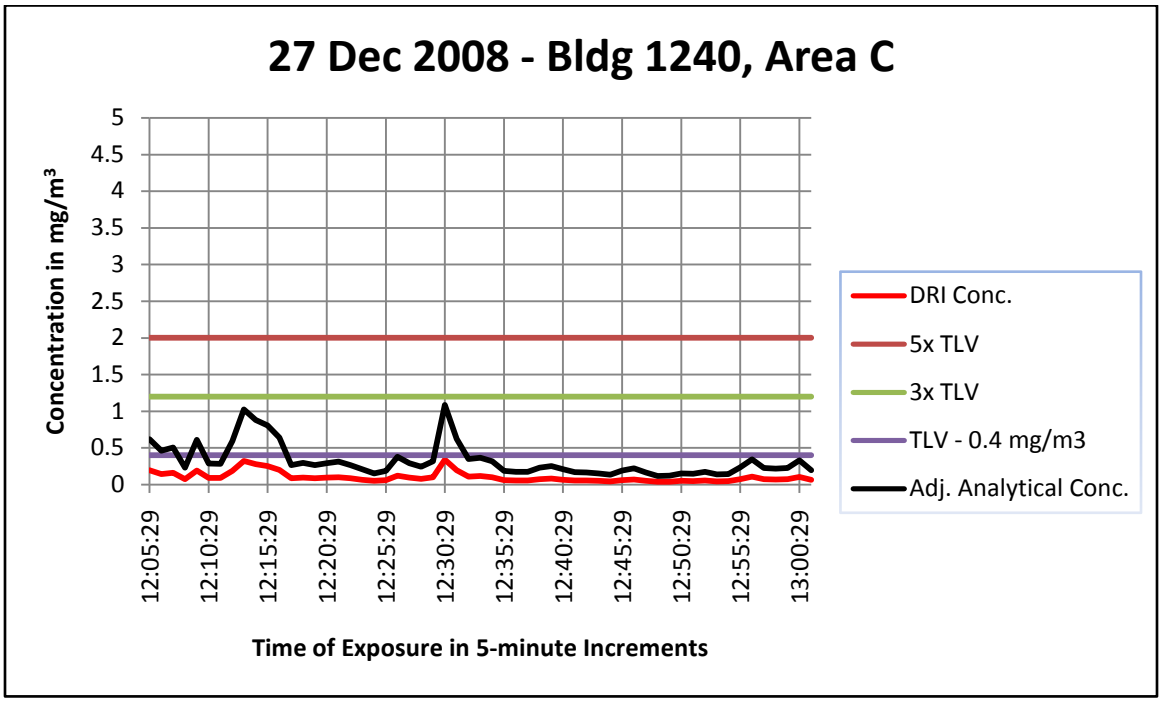

25 Dec 2008 - Bldg 770, Area B
Concentration in mg/m³
5
4.5
4
3.5
3
2.5
2
1.5
1
0.5
0
07:25:42
07:30:42
07:35:42
07:40:42
07:45:42
07:50:42
07:55:42
08:00:42
08:05:42
08:10:42
08:15:42
08:20:42
08:25:42
08:30:42
08:35:42
08:40:42
08:45:42
08:50:42
08:55:42
09:00:42
Time of Exposure in 5-minute Increments
DRI Conc.
5x TLV
3x TLV
TLV - 0.4 mg/m3
Adj. Analytical Conc.

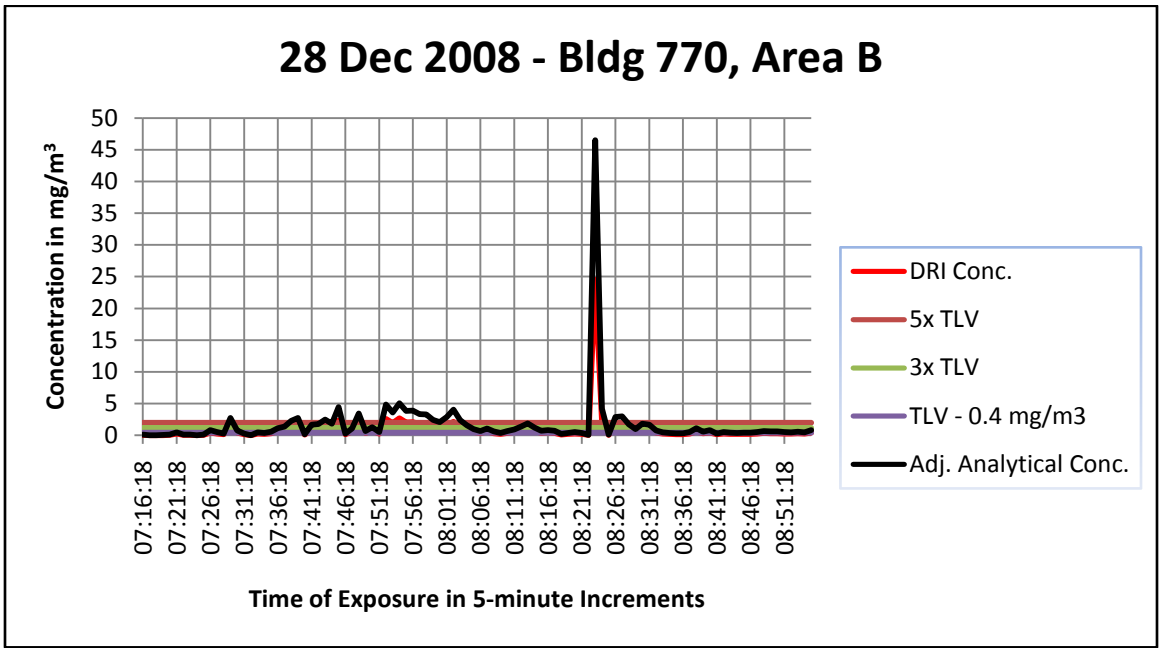

25 Dec 2008 - Bldg 1240, Area C
Concentration in mg/m³
5
4.5
4
3.5
3
2.5
2
1.5
1
0.5
0
12:03:31
12:08:31
12:13:31
12:18:31
12:23:31
12:28:31
12:33:31
12:38:31
12:43:31
12:48:31
Time of Exposure in 5-minute Increments
DRI Conc.
5x TLV
3x TLV
TLV - 0.4 mg/m3
Adj. Analytical Conc.

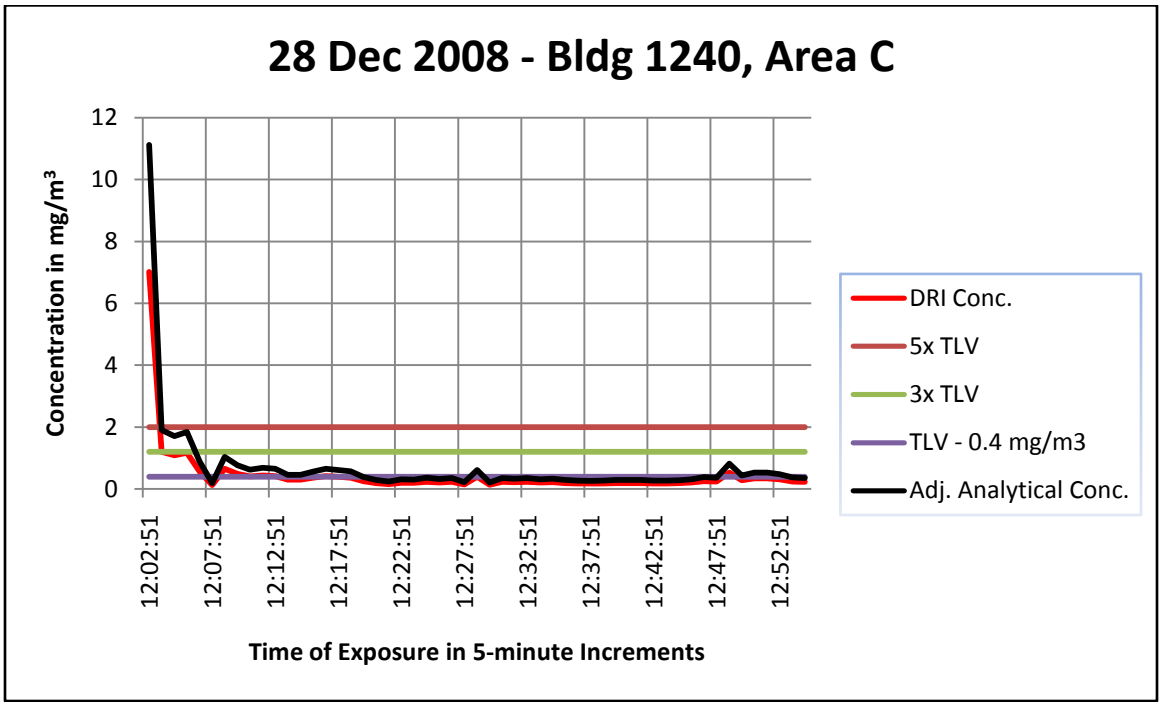

26 Dec 2008 - Bldg 770, Area B
Concentration in mg/m³
120
100
80
60
40
20
0
07:22:56
07:27:56
07:32:56
07:37:56
07:42:56
07:47:56
07:52:56
7:57
8:02
8:07
8:12
8:17
08:22:43
08:27:43
08:32:43
08:37:43
08:42:43
08:47:43
08:52:43
08:57:43
09:02:43
09:07:43
09:12:43
09:17:43
09:22:43
09:27:43
09:32:43
09:37:43
09:42:43
Time of Exposure in 5-minute Increments
DRI Conc.
5x TLV
3x TLV
TLV - 0.4 mg/m3
Adj. Analytical Conc.

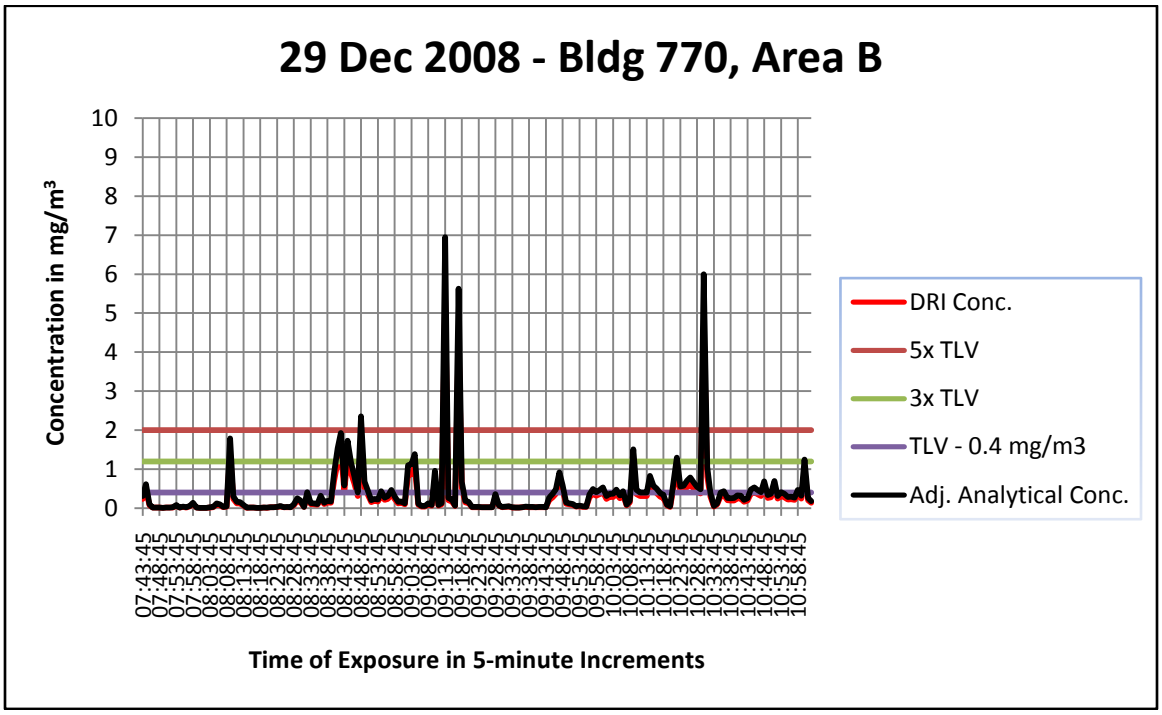

26 Dec 2008 - Bldg 1240, Area C
Concentration in mg/m³
5
4.5
4
3.5
3
2.5
2
1.5
1
0.5
0
12:04:39
12:09:39
12:14:39
12:19:39
12:24:39
12:29:39
12:34:39
12:39:39
12:44:39
12:49:39
12:54:39
12:59:39
Time of Exposure in 5-minute Increments
DRI Conc.
5x TLV
3x TLV
TLV - 0.4 mg/m3
Adj. Analytical Conc.

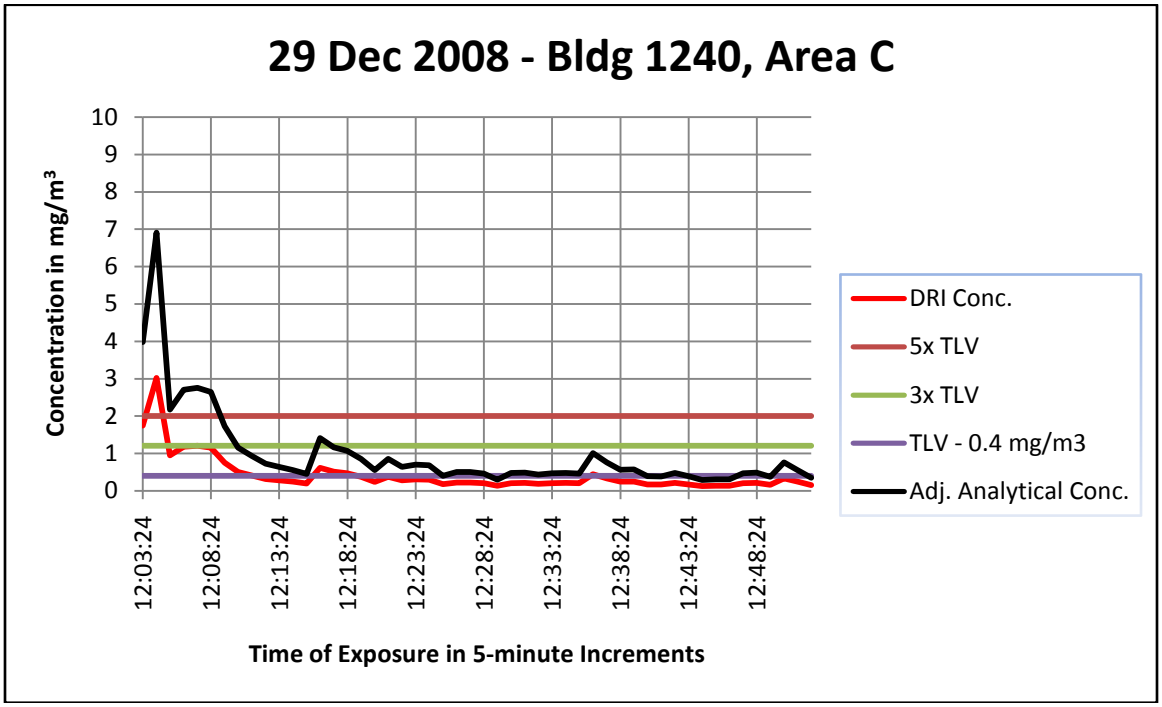

27 Dec 2008 - Bldg 770, Area B
Concentration in mg/m³
5
4.5
4
3.5
3
2.5
2
1.5
1
0.5
0
07:15:24
07:20:24
07:25:24
07:30:24
07:35:24
07:40:24
07:45:24
07:50:24
07:55:24
08:00:24
08:05:24
Time of Exposure in 5-minute Increments
DRI Conc.
5x TLV
3x TLV
TLV - 0.4 mg/m3
Adj. Analytical Conc.

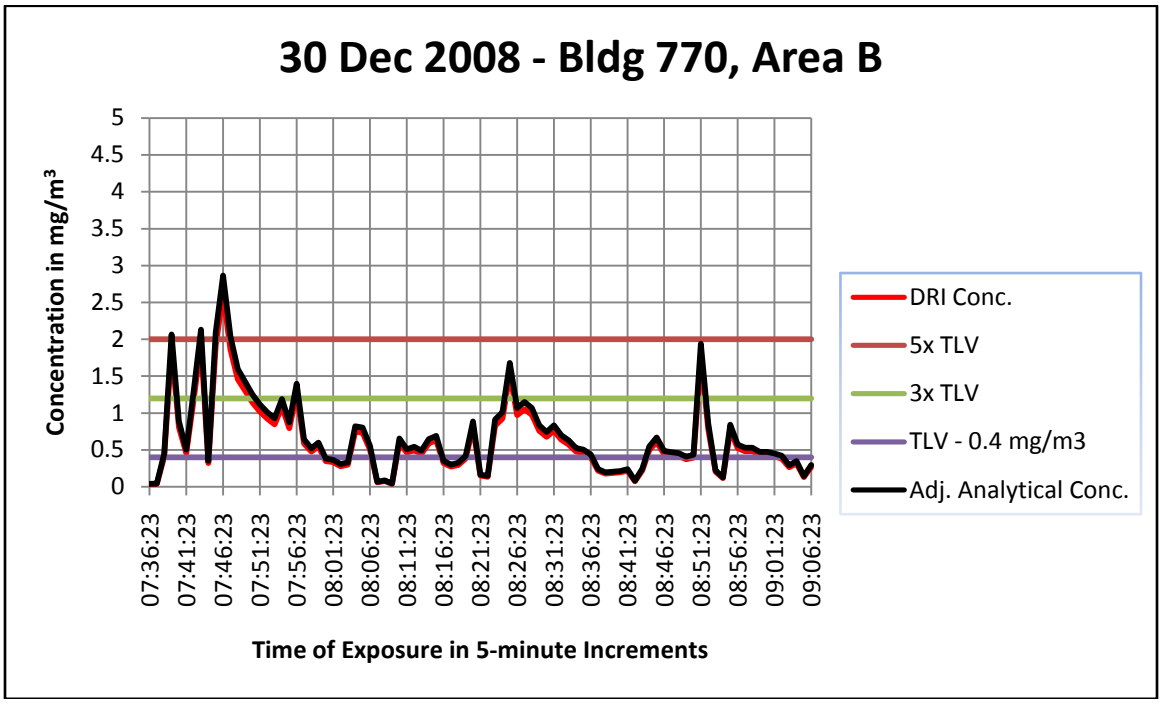

27 Dec 2008 - Bldg 1240, Area C
Concentration in mg/m³
5
4.5
4
3.5
3
2.5
2
1.5
1
0.5
0
12:05:29
12:10:29
12:15:29
12:20:29
12:25:29
12:30:29
12:35:29
12:40:29
12:45:29
12:50:29
12:55:29
13:00:29
Time of Exposure in 5-minute Increments
DRI Conc.
5x TLV
3x TLV
TLV - 0.4 mg/m3
Adj. Analytical Conc.

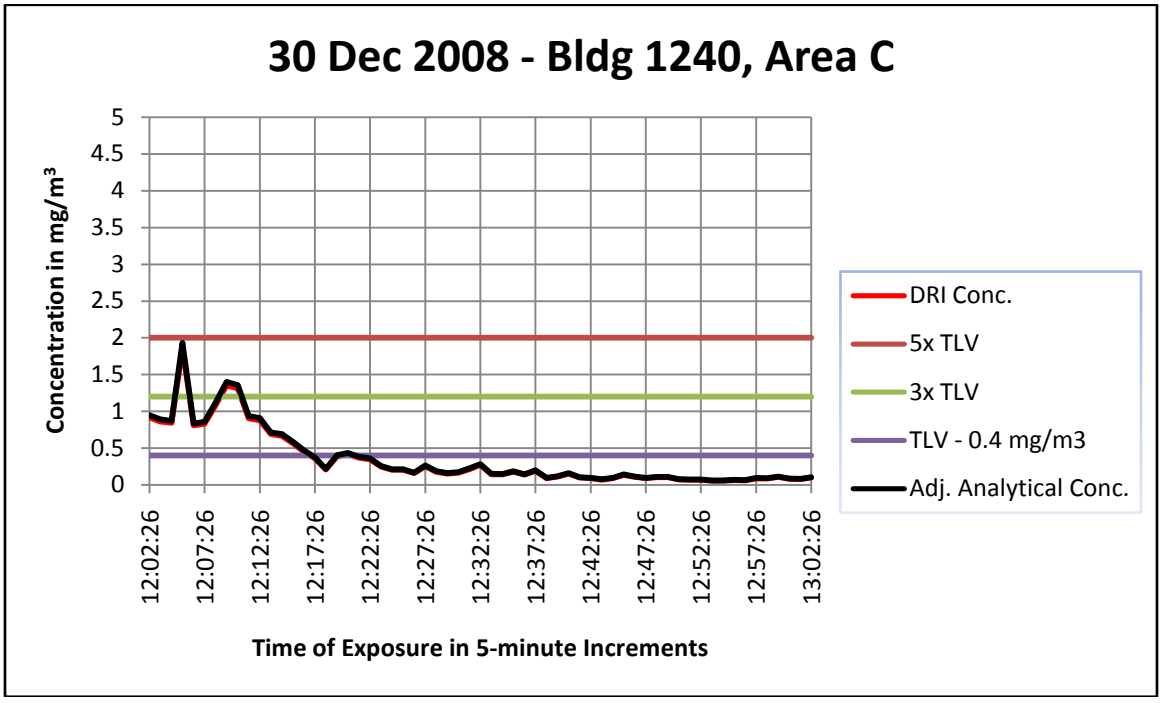

28 Dec 2008 - Bldg 770, Area B
Concentration in mg/m³
50
45
40
35
30
25
20
15
10
5
0
07:16:18
07:21:18
07:26:18
07:31:18
07:36:18
07:41:18
07:46:18
07:51:18
07:56:18
08:01:18
08:06:18
08:11:18
08:16:18
08:21:18
08:26:18
08:31:18
08:36:18
08:41:18
08:46:18
08:51:18
Time of Exposure in 5-minute Increments
DRI Conc.
5x TLV
3x TLV
TLV - 0.4 mg/m3
Adj. Analytical Conc.

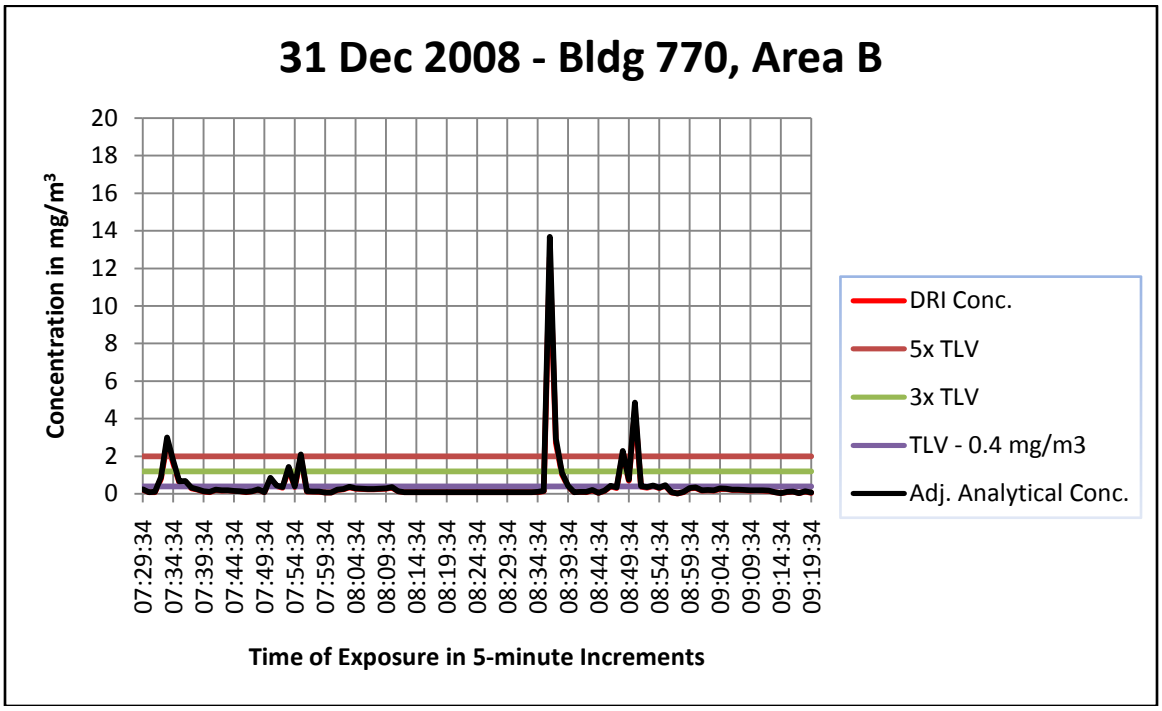

28 Dec 2008 - Bldg 1240, Area C
Concentration in mg/m³
12
10
8
6
4
2
0
12:02:51
12:07:51
12:12:51
12:17:51
12:22:51
12:27:51
12:32:51
12:37:51
12:42:51
12:47:51
12:52:51
Time of Exposure in 5-minute Increments
DRI Conc.
5x TLV
3x TLV
TLV - 0.4 mg/m3
Adj. Analytical Conc.

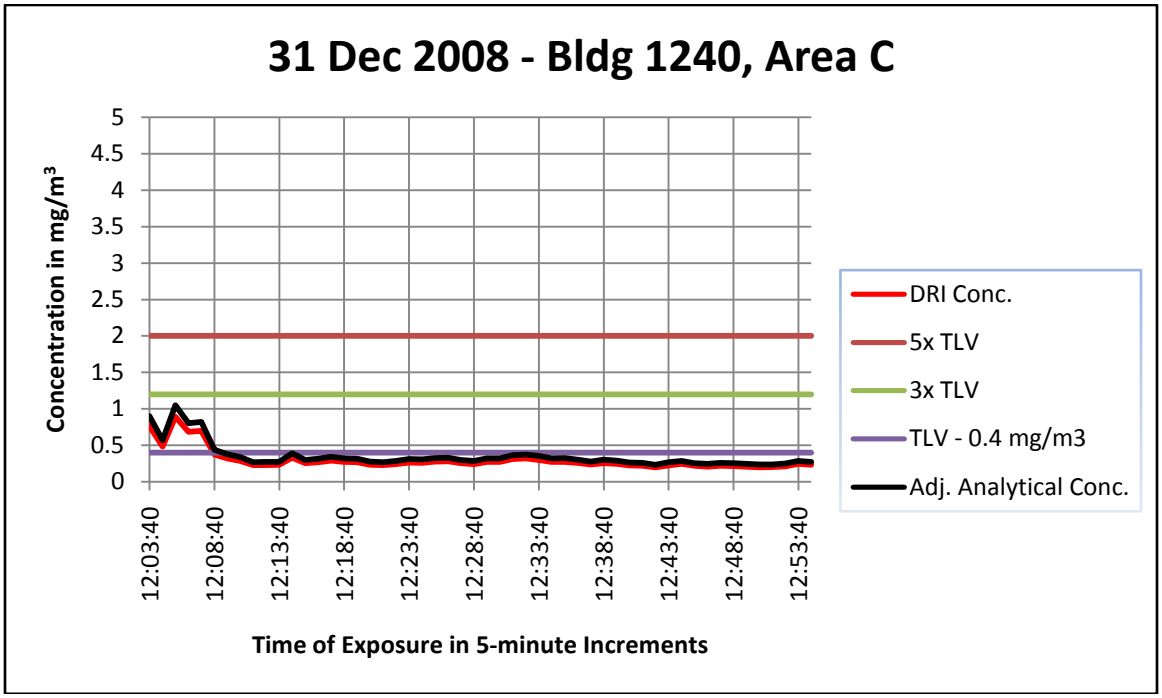

29 Dec 2008 - Bldg 770, Area B
Concentration in mg/m³
10
9
8
7
6
5
4
3
2
1
0
07:43:45
07:48:45
07:53:45
07:58:45
08:03:45
08:08:45
08:13:45
08:18:45
08:23:45
08:28:45
08:33:45
08:38:45
08:43:45
08:48:45
08:53:45
08:58:45
09:03:45
09:08:45
09:13:45
09:18:45
09:23:45
09:28:45
09:33:45
09:38:45
09:43:45
09:48:45
09:53:45
09:58:45
10:03:45
10:08:45
10:13:45
10:18:45
10:23:45
10:28:45
10:33:45
10:38:45
10:43:45
10:48:45
10:53:45
10:58:45
Time of Exposure in 5-minute Increments
DRI Conc.
5x TLV
3x TLV
TLV - 0.4 mg/m3
Adj. Analytical Conc.

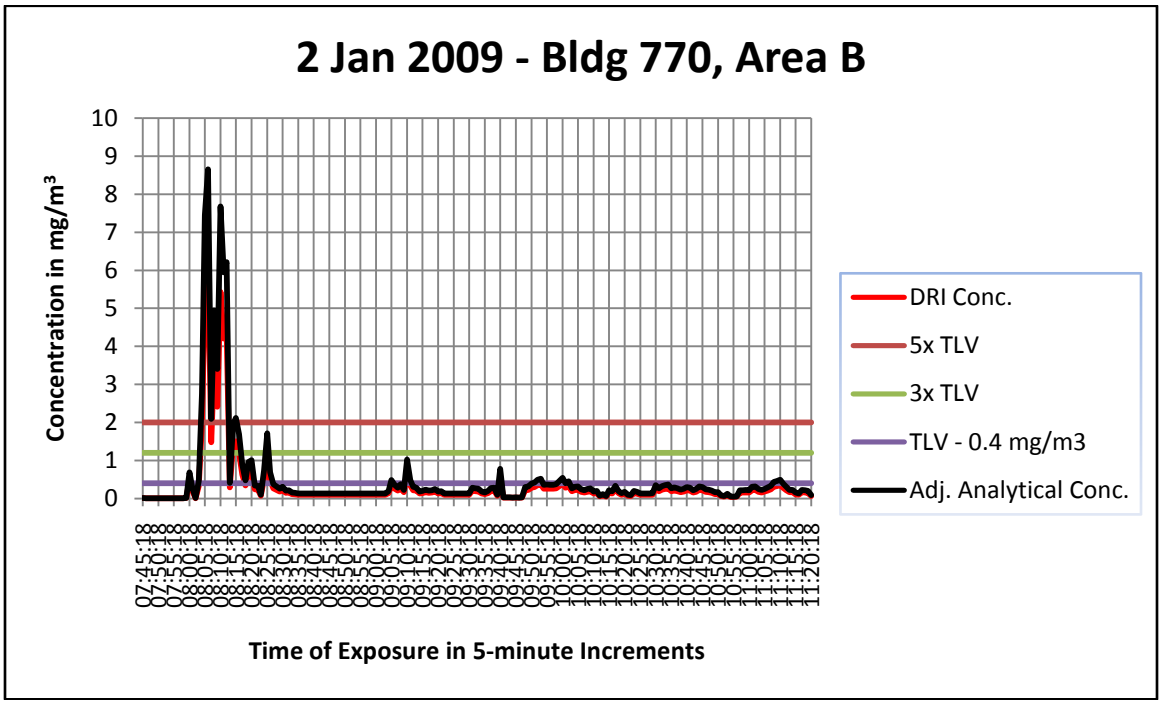

29 Dec 2008 - Bldg 1240, Area C
Concentration in mg/m³
10
9
8
7
6
5
4
3
2
1
0
12:03:24
12:08:24
12:13:24
12:18:24
12:23:24
12:28:24
12:33:24
12:38:24
12:43:24
12:48:24
Time of Exposure in 5-minute Increments
DRI Conc.
5x TLV
3x TLV
TLV - 0.4 mg/m3
Adj. Analytical Conc.

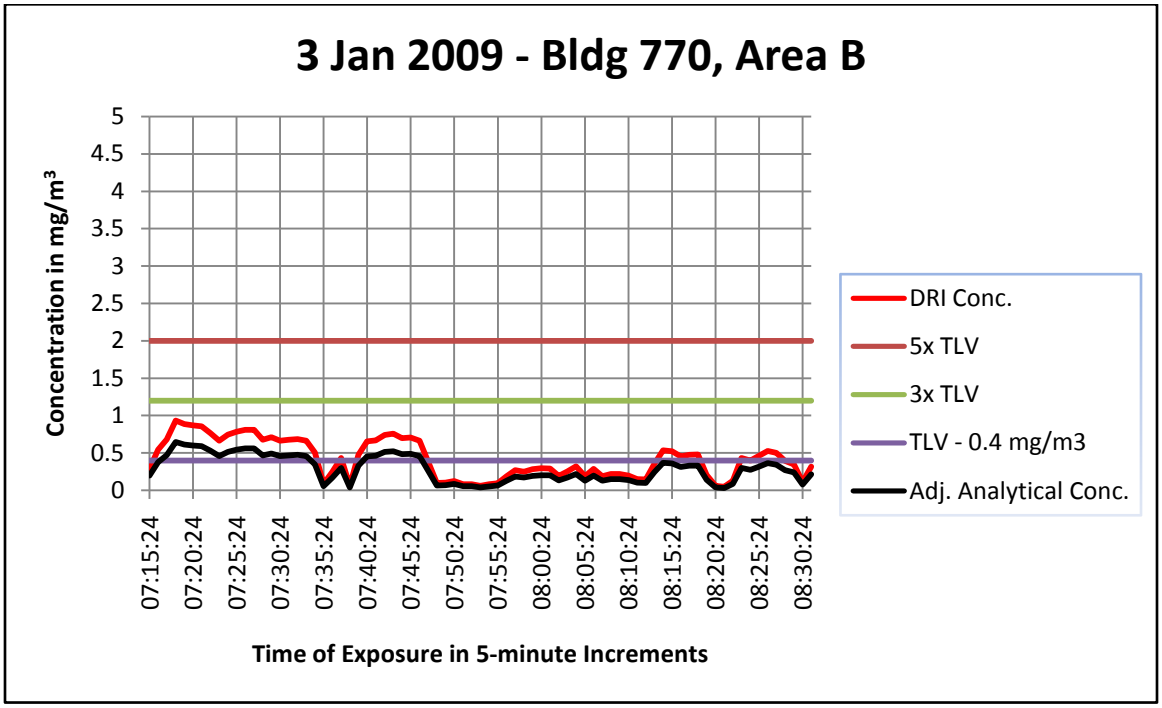

30 Dec 2008 - Bldg 770, Area B
Concentration in mg/m³
5
4.5
4
3.5
3
2.5
2
1.5
1
0.5
0
07:36:23
07:41:23
07:46:23
07:51:23
07:56:23
08:01:23
08:06:23
08:11:23
08:16:23
08:21:23
08:26:23
08:31:23
08:36:23
08:41:23
08:46:23
08:51:23
08:56:23
09:01:23
09:06:23
Time of Exposure in 5-minute Increments
DRI Conc.
5x TLV
3x TLV
TLV - 0.4 mg/m3
Adj. Analytical Conc.

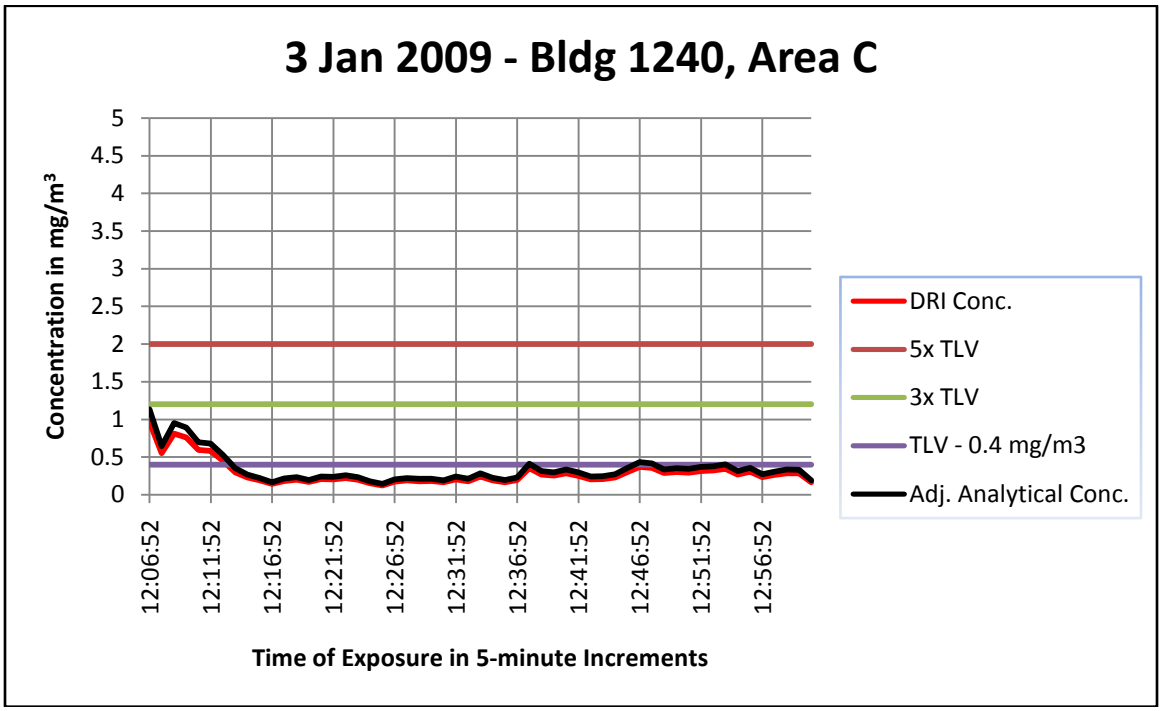

30 Dec 2008 - Bldg 1240, Area C
Concentration in mg/m³
5
4.5
4
3.5
3
2.5
2
1.5
1
0.5
0
12:02:26
12:07:26
12:12:26
12:17:26
12:22:26
12:27:26
12:32:26
12:37:26
12:42:26
12:47:26
12:52:26
12:57:26
13:02:26
Time of Exposure in 5-minute Increments
DRI Conc.
5x TLV
3x TLV
TLV - 0.4 mg/m3
Adj. Analytical Conc.

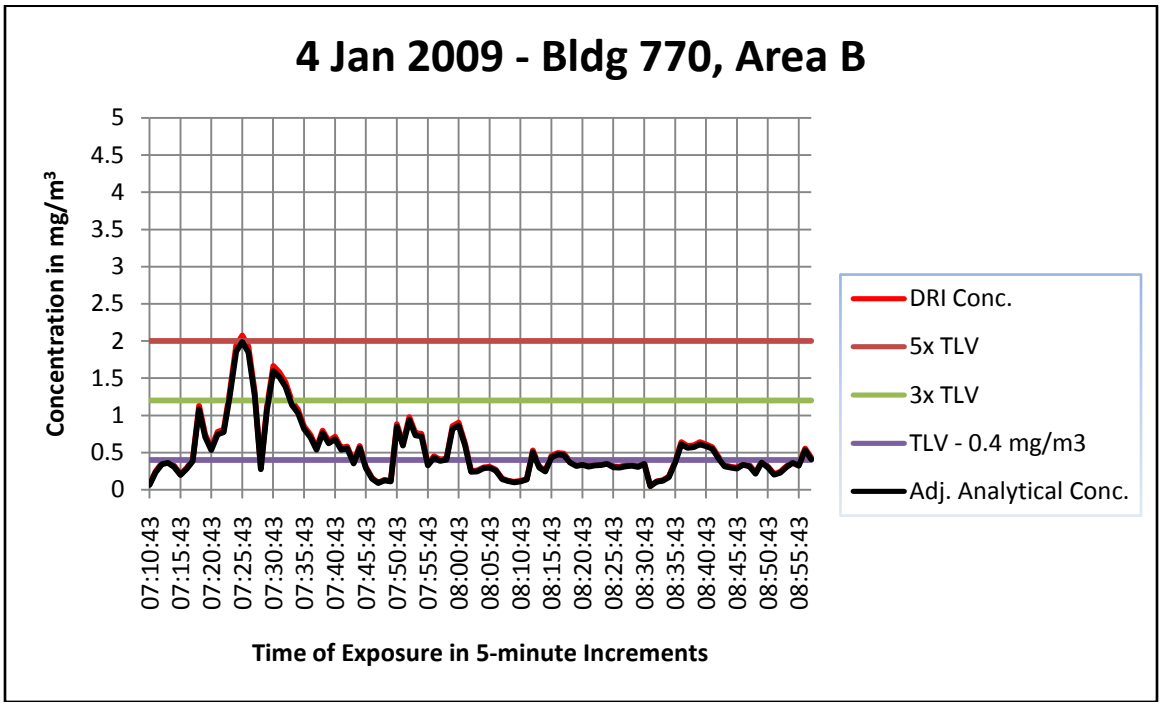

31 Dec 2008 - Bldg 770, Area B
Concentration in mg/m³
20
18
16
14
12
10
8
6
4
2
0
07:29:34
07:34:34
07:39:34
07:44:34
07:49:34
07:54:34
07:59:34
08:04:34
08:09:34
08:14:34
08:19:34
08:24:34
08:29:34
08:34:34
08:39:34
08:44:34
08:49:34
08:54:34
08:59:34
09:04:34
09:09:34
09:14:34
09:19:34
Time of Exposure in 5-minute Increments
DRI Conc.
5x TLV
3x TLV
TLV - 0.4 mg/m3
Adj. Analytical Conc.

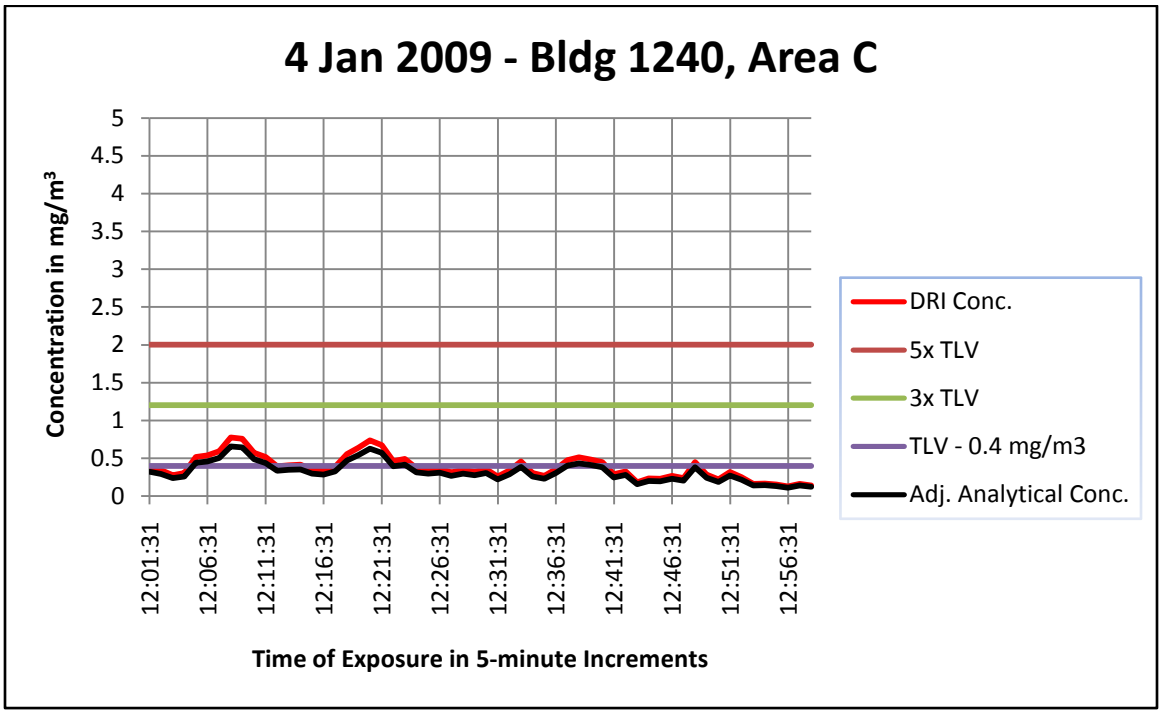

31 Dec 2008 - Bldg 1240, Area C
Concentration in mg/m³
5
4.5
4
3.5
3
2.5
2
1.5
1
0.5
0
12:03:40
12:08:40
12:13:40
12:18:40
12:23:40
12:28:40
12:33:40
12:38:40
12:43:40
12:48:40
12:53:40
Time of Exposure in 5-minute Increments
DRI Conc.
5x TLV
3x TLV
TLV - 0.4 mg/m3
Adj. Analytical Conc.


2 Jan 2009 - Bldg 770, Area B
Concentration in mg/m³
Time of Exposure in 5-minute Increments
DRI Conc.
5x TLV
3x TLV
TLV - 0.4 mg/m3
Adj. Analytical Conc.


3 Jan 2009 - Bldg 770, Area B
Concentration in mg/m³
Time of Exposure in 5-minute Increments
DRI Conc.
5x TLV
3x TLV
TLV - 0.4 mg/m3
Adj. Analytical Conc.


3 Jan 2009 - Bldg 1240, Area C
Concentration in mg/m³
5
4.5
4
3.5
3
2.5
2
1.5
1
0.5
0
12:06:52
12:11:52
12:16:52
12:21:52
12:26:52
12:31:52
12:36:52
12:41:52
12:46:52
12:51:52
12:56:52
Time of Exposure in 5-minute Increments
DRI Conc.
5x TLV
3x TLV
TLV - 0.4 mg/m3
Adj. Analytical Conc.


4 Jan 2009 - Bldg 770, Area B
Concentration in mg/m³
5
4.5
4
3.5
3
2.5
2
1.5
1
0.5
0
07:10:43
07:15:43
07:20:43
07:25:43
07:30:43
07:35:43
07:40:43
07:45:43
07:50:43
07:55:43
08:00:43
08:05:43
08:10:43
08:15:43
08:20:43
08:25:43
08:30:43
08:35:43
08:40:43
08:45:43
08:50:43
08:55:43
Time of Exposure in 5-minute Increments
DRI Conc.
5x TLV
3x TLV
TLV - 0.4 mg/m3
Adj. Analytical Conc.


4 Jan 2009 - Bldg 1240, Area C
Concentration in mg/m³
5
4.5
4
3.5
3
2.5
2
1.5
1
0.5
0
12:01:31
12:06:31
12:11:31
12:16:31
12:21:31
12:26:31
12:31:31
12:36:31
12:41:31
12:46:31
12:51:31
12:56:31
Time of Exposure in 5-minute Increments
DRI Conc.
5x TLV
3x TLV
TLV - 0.4 mg/m3
Adj. Analytical Conc.

Appendix D: Tabulated Sample Data

This appendix is a collection of the detailed sample data regarding the exposure assessment of the coal workers. Table D1, is a list of the pre- and post-calibration flow rates of the sampling pump used to collect the coal dust samples. Table D2 applies the pre-calibration flow rate with the task duration to calculate the volume of air sampled. Table D3 is a register of the task TWA provided by the analytical lab and the 8-hour TWA, which is a weighted average, based on the task TWA times the duration of exposure and a zero concentration times the remaining unexposed duration divided by 8 hours. Table D4 is an evaluation of the task TWA and the 8-hour TWA regarding the ACGIH® TLV®. Table D5 is the same evaluation regarding ACGIH® excursion limits. Lastly, Table D6 is a summary of relative humidity data lost.

Table D1: GilAir5® Flow Pump Calibration

Date Calibrated	Flow Rate (L/min)		
	Pre-Cal	Post-Cal	Post-Cal +/- 10%
17-Dec	2.775	2.920	YES
19-Dec	2.689	2.539	YES
22-Dec	2.767	2.900	YES
23-Dec	2.724	2.564	YES
24-Dec	2.688	2.669	YES
25-Dec	2.730	2.824	YES
26-Dec	2.676	2.711	YES
27-Dec	2.706	2.616	YES
28-Dec	2.655	2.703	YES
29-Dec	2.673	2.700	YES
30-Dec	2.721	2.603	YES
31-Dec	2.713	2.767	YES
2-Jan	2.731	2.710	YES
3-Jan	2.696	2.698	YES
4-Jan	2.715	2.631	YES

Table D2: GilAir5® Flow Pump Volumes

Date Collected	Start Time	Stop Time	Duration (minutes)	Volume (Liters)
17-Dec	915	1148	153	424.6
19-Dec	747	958	131	352.3
19-Dec	1138	1231	53	142.5
22-Dec	735	1055	200	553.4
23-Dec	740	1009	149	405.9
23-Dec	1201	1320	79	215.2
24-Dec	1157	1236	39	104.8
25-Dec	724	901	97	264.8
25-Dec	1202	1250	48	131.0
26-Dec	722	942	141	377.3
26-Dec	1203	1302	59	157.9
27-Dec	714	805	51	138.0
27-Dec	1204	1301	57	154.2
28-Dec	715	855	100	265.5
28-Dec	1202	1255	53	140.7
29-Dec	742	1102	200	534.6
29-Dec	1202	1252	50	133.7
30-Dec	735	906	91	247.6
30-Dec	1201	1302	61	166.0
31-Dec	728	897	89	241.5
31-Dec	1202	1254	52	141.1
2-Jan	744	1038	174	475.2
3-Jan	714	831	77	207.6
3-Jan	1205	1300	55	148.3
4-Jan	735	923	108	293.2
4-Jan	1200	1338	58	157.5

Table D3: Task and 8-Hour TWA Concentration Results of Analytical Samples

Date Collected	Task Conc. (mg/m^3)	Task Duration (minutes)	8-hr TWA	Task Conc.> 0.4 mg/m^3	8-hr TWA > 0.4 mg/m^3
17-Dec	0.59	153	0.188	YES	-
19-Dec	0.43	131	0.117	YES	-
19-Dec	0.35	53	0.039	-	-
22-Dec	5.1	200	2.125	YES	YES
23-Dec	0.32	149	0.099	-	-
23-Dec	0.23	79	0.038	-	-
24-Dec	0.48	39	0.039	YES	-
25-Dec	0.91	97	0.184	YES	-
25-Dec	0.38	48	0.038	-	-
26-Dec	3.71	141	1.090	YES	YES
26-Dec	0.63	59	0.077	YES	-
27-Dec	0.94	51	0.100	YES	-
27-Dec	0.32	57	0.038	-	-
28-Dec	1.7	100	0.354	-	YES
28-Dec	0.71	53	0.078	-	-
29-Dec	0.41	200	0.171	-	YES
29-Dec	0.97	50	0.101	-	YES
30-Dec	0.69	91	0.131	-	YES
30-Dec	0.36	61	0.046	-	-
31-Dec	0.498	89	0.115	-	YES
31-Dec	0.35	52	0.038	-	-
2-Jan	0.484	174	0.218	-	YES
3-Jan	0.29	77	0.047	-	-
3-Jan	0.34	55	0.039	-	-
4-Jan	0.51	108	0.115	-	YES
4-Jan	0.32	58	0.039	-	-

Table D4: Task and 8-Hour TWA Concentration Results of DRI Samples

Date Collected	Correction Factor Equating DRI to Analytical	Task Conc. (mg/m^3)	8-hr TWA	Task Conc. > 0.4 mg/m^3	8-hr TWA > 0.4 mg/m^3
17-Dec	1.074	0.549	0.175	YES	-
19-Dec	1.129	0.381	0.104	-	-
19-Dec	1.470	0.238	0.026	-	-
22-Dec	1.653	3.086	1.286	YES	YES
23-Dec	0.863	0.371	0.115	-	-
23-Dec	0.580	0.397	0.065	-	-
24-Dec	3.506	0.137	0.011	-	-
25-Dec	1.088	0.837	0.169	YES	-
25-Dec	1.897	0.200	0.020	-	-
26-Dec	2.493	1.488	0.437	YES	YES
26-Dec	1.255	0.502	0.062	YES	-
27-Dec	1.408	0.668	0.071	YES	-
27-Dec	3.196	0.100	0.014	-	-
28-Dec	1.896	0.897	0.187	YES	-
28-Dec	1.586	0.448	0.049	YES	-
29-Dec	1.303	0.315	0.131	-	-
29-Dec	2.292	0.423	0.044	YES	-
30-Dec	1.095	0.630	0.119	YES	-
30-Dec	1.032	0.349	0.044	-	-
31-Dec	1.086	0.459	0.106	YES	-
31-Dec	1.179	0.297	0.032	-	-
2-Jan	1.414	0.342	0.154	-	-
3-Jan	0.693	0.418	0.067	YES	-
3-Jan	1.170	0.291	0.033	-	-
4-Jan	0.960	0.532	0.120	YES	-
4-Jan	0.847	0.378	0.046	-	-

Table D5: Excursion Limit Results for DRI and Analytical Samples (A.S.)

Date Collected	DRI > 3x TLV®	A.S. > 3x TLV®	DRI > 5x TLV®	A.S. > 5x TLV®
17-Dec	-	-	YES	YES
19-Dec	-	-	-	-
19-Dec	-	-	-	YES
22-Dec	YES	YES	YES	YES
23-Dec	-	-	-	-
23-Dec	-	-	-	-
24-Dec	-	-	-	-
25-Dec	-	-	YES	YES
25-Dec	-	-	-	-
26-Dec	-	-	YES	YES
26-Dec	-	-	-	YES
27-Dec	-	-	YES	YES
27-Dec	-	-	-	-
28-Dec	-	-	YES	YES
28-Dec	-	-	YES	YES
29-Dec	-	-	YES	YES
29-Dec	-	-	YES	YES
30-Dec	-	-	YES	YES
30-Dec	-	-	-	-
31-Dec	-	-	YES	YES
31-Dec	-	-	-	-
2-Jan	-	-	YES	YES
3-Jan	-	-	-	-
3-Jan	-	-	-	-
4-Jan	-	-	YES	YES
4-Jan	-	-	-	-

Table D6: Summary of Relative Humidity Data Lost

Date Collected	Location	Total Minutes	Minutes Lost
17-Dec	Area B	153	2
26-Dec	Area B	141	8
27-Dec	Area B	51	7
28-Dec	Area B	100	1
30-Dec	Area B	91	3
30-Dec	Area C	61	2
31-Dec	Area B	111	4
2-Jan	Area B	216	1
3-Jan	Area B	77	2
4-Jan	Area B	108	6
4-Jan	Area C	58	3

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14. ABSTRACT

An exposure assessment strategy (EAS) determines the number of samples required to characterize an occupational health exposure's acceptability. A novel EAS (AFIT-EAS) was developed with the objective of maximizing the sensitivity for detecting unacceptable exposures, while minimizing the total number of samples needed. The purpose of this field evaluation was to use data from a comprehensive sampling campaign (SC) to compare the AFIT-EAS with two commonly used EASs: the Occupational Safety and Health Administration's (OSHA-EAS) and the American Industrial Hygiene Association's (AIHA-EAS). 10 randomly sampled replicates were selected from the SC. The number of samples selected per replicate was in accordance with each respective EAS's protocol. Results show that the true health risk assessment for the SC was evaluated as unacceptable; therefore, EAS conclusions matching this result were counted as successful. The OSHA-EAS of one (1) sample per replicate was the least successful with a maximum success rate of 20%. The AIHA-EAS of six (6) samples per replicate was equal to the AFIT-EAS of three (3) samples per replicate with a maximum success rate of 100%. The AFIT-EAS was found to be more accurate than the OSHA-EAS and equally accurate as the AIHA-EAS, while using only half as many samples.

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